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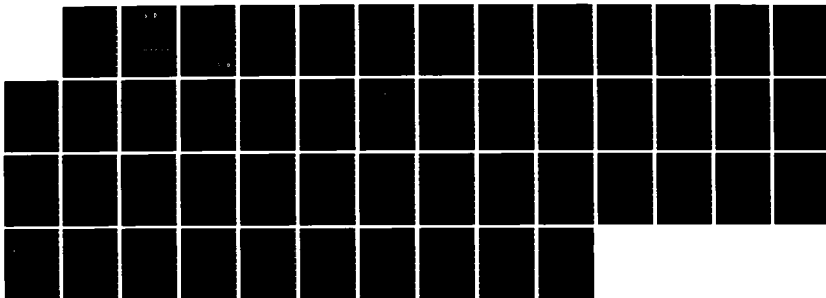
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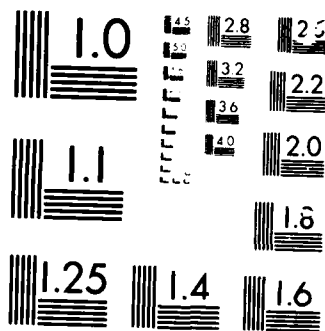
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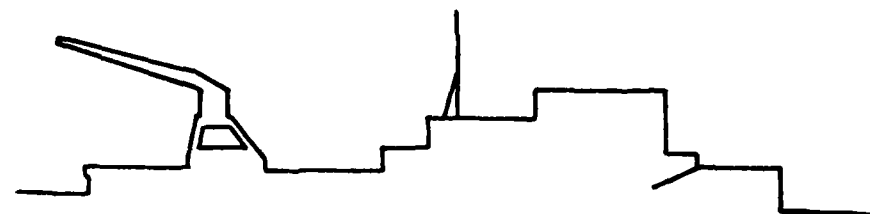
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PHYSICAL ENVIRONMENT OF THE  
PACIFIC MISSILE RANGE FACILITY,  
KAUAI, HAWAII

by Philip Vitale

FPO-1-84(5)  
March 1984



# Ocean Engineering

CHESAPEAKE DIVISION  
NAVAL FACILITIES ENGINEERING COMMAND  
WASHINGTON NAVY YARD  
WASHINGTON, DC 20374

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APPROVED BY:

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This report presents the physical environment of the Pacific Missile Range Facility (PMRF), Kauai, Hawaii. The purpose of the report is to provide information to support future engineering efforts to protect the marine cables which come ashore at the PMRF. (Con't)

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The climate is mild and dry with only two meteorological seasons. Summer is April through November and is a time of strong northeast trade winds. Winter is December through March, and is a time of lessening trade winds but increasing southeasterly winds and local storms. The waves are composed of northeast trade waves, North Pacific swell, southern swell, and Kona storm waves. Fifteen years of surf observations show the summer months to have a much milder wave climate than the winter months.

The beach sand is medium size, poorly-sorted, and tends to move offshore during the winter and onshore during the summer. Beachrock is prevalent and extends out to 200 feet offshore. A boring study has shown the beachrock at the shoreline to be 7.5 to 14.5 feet thick and of compressive strengths of 3,000 to 11,000 psi. The rock prevents cable from being buried without considerable drilling and trenching. The literature reports that the area immediately northeast of the cable landing area has no beachrock. If this is true, or if the beachrock is deep enough below the sand level that it is infrequently exposed, then the cables can be easily and safely buried in the sand. The next step in pursuing this option is a boring or probing study of the area northeast of the cable landing area.

The best time of year to work at the PMRF cable landing site with regard to the wave environment is the summer, particularly during June, July, and August. However, summer is also the time of maximum beach sand thickness which makes work on the beachrock difficult. Therefore, if both large waves and beach sand are to be avoided, the early summer months of April and May are probably optimum. During these months, the waves are relatively low and the beach sand has not much time to move back onshore.

## EXECUTIVE SUMMARY

This report presents the physical environment of the Pacific Missile Range Facility (PMRF), Kauai, Hawaii. The purpose of the report is to provide information to support future engineering efforts to protect the marine cables which come ashore at the PMRF.

The climate is mild and dry with only two meteorological seasons. Summer is April through November and is a time of strong northeast trade winds. Winter is December through March, and is a time of lessening trade winds but increasing southeasterly winds and local storms. The waves are composed of northeast trade waves, North Pacific swell, southern swell, and Kona storm waves. Fifteen years of surf observations show the summer months to have a much milder wave climate than the winter months.

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## I. INTRODUCTION

This report describes the physical environment at the Pacific Missile Range Facility (PMRF), Kauai, Hawaii. Figure 1 is a location map. The purpose of the report is to provide information which can be used to better protect present and future cable landings at the PMRF.

Information needed for proper design of cable protection includes wind data, wave data, nearshore current estimates, longshore and onshore-offshore sand transport estimates, and geotechnical data. The National Climatic Data Center has provided summaries of six years of wind data collected at the PMRF. Wave data are less abundant and are contained in several sources: the wave climate put together by Marine Advisers (1964); the daily visual observations made at the PMRF since 1968; and an offshore wave gage installed in October 1982. Limited nearshore current data are available from several references. Geotechnical information was particularly scarce so a program of data collection was planned and executed. Three 30-foot borings were taken on the beach to provide information primarily about the depth and strength of the beachrock indigenous to the PMRF cable landing area.

In this report, the climate of the study area, including precipitation and temperature, is discussed. Wind and wave data are tabulated and analyzed with directional and seasonal trends identified. The geology of the region is briefly summarized with particular emphasis on beachrock, which seems to be the indirect cause of most of the cable problems. The sediment budget is described and includes an identification of sand sources and sand movement directions. The conclusions include a summary of design considerations and some recommendations for future work.



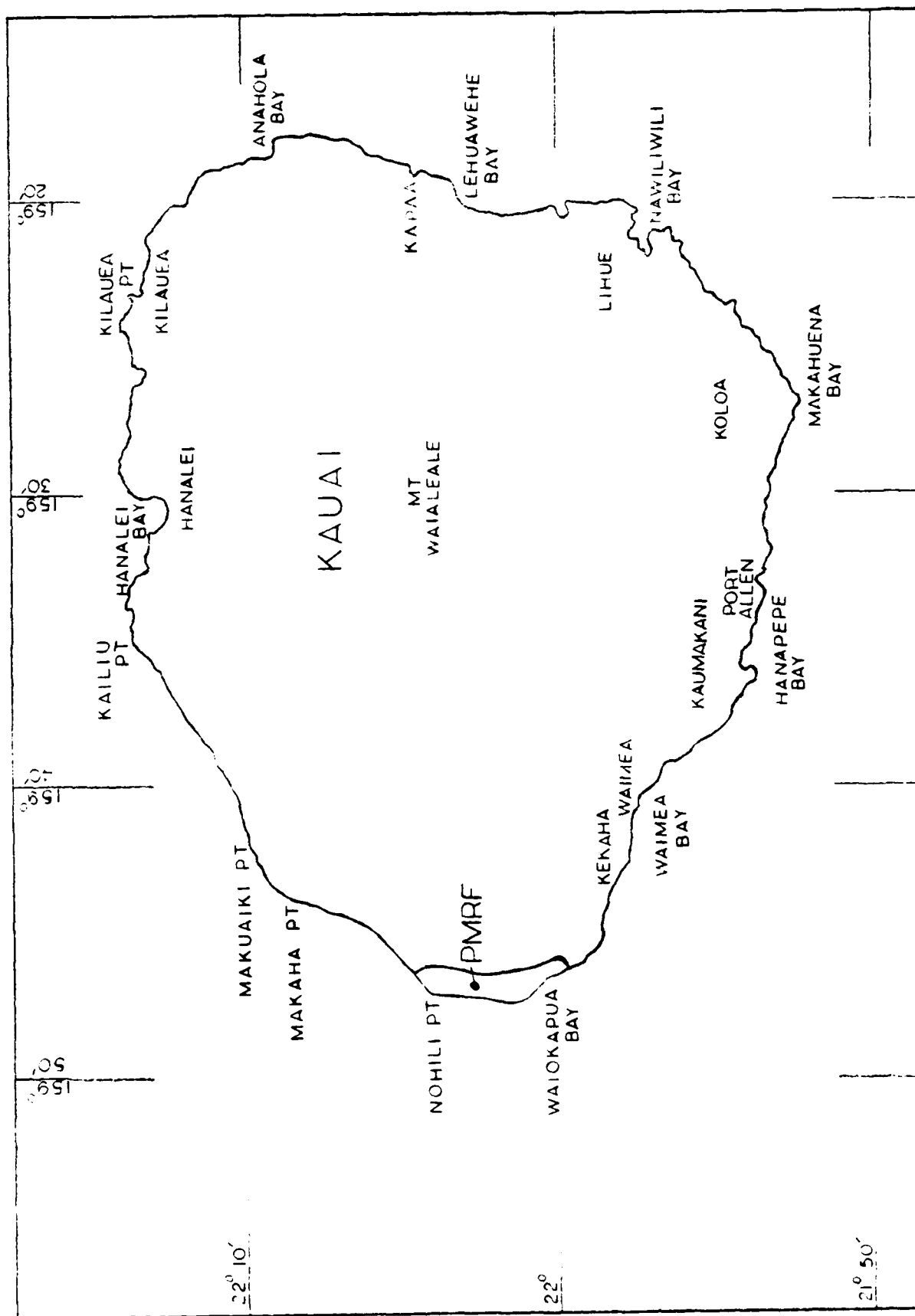


FIGURE 1: LOCATION MAP, PACIFIC MISSILE RANGE FACILITY, KAUAI, HAWAII.

## II. CLIMATE

The island of Kauai lies just south of the Tropic of Cancer within the northeast trade wind zone. The climate is generally mild due to the surrounding ocean and only two meteorological seasons are noticeable. Summer runs from April through November and is characterized by the strong northeast trade winds; winter brings a weakening of these trade winds and the appearance of southwesterly winds and fronts from the north temperate zone (Marine Advisers, 1964).

As shown in Figure 2 from Macdonald, Davis, and Cox (1960), the amount of rainfall varies widely over the island due to the influence of Mt. Waialeale. As the moist trade winds move over the mountain, they rise into the cooler, higher elevations. The cooler temperatures cause the air to lose much of its moisture in the form of rain. This type of precipitation is known as orographic precipitation, which is also responsible for the rains of the Pacific Northwest (Viessman, et al., 1977). The areas to the west of the Mt. Waialeale range, therefore, receive much less precipitation than the rest of the island.

For example, the annual rainfall at the Mana station (1026 on Figure 2) on the west side of the island, which is close to the PMRF, is 21.58 inches. At the Mt. Waialeale station (1047 on Figure 2) the annual rainfall is 466 inches. Figure 3 shows the monthly precipitation values at the Mana station based on data from Macdonald, Davis, and Cox (1960). The wet months are the winter months of December through March.

The temperature of the island varies little over the year. The mean yearly temperature at the Mana station is 74.2 °F, with a range in mean monthly temperatures of 70.1 °F in January to 78.1 °F in August. Figure 3 is a plot of the mean monthly temperature for the Mana station based on data from Macdonald, Davis, and Cox (1960).

Tropical storms are cyclonic disturbances of tropical origin in which maximum sustained winds have exceeded 34 knots. Hurricanes are similarly defined but with sustained winds exceeding 64 knots. An analysis in Crutcher and Quale (1974) of seven years of data shows no well-defined tropical storms or hurricanes in the 50 latitude-longitude square in which Kauai is located. The adjacent 50 square, however, shows an approximately 11% chance of a tropical storm or hurricane heading toward Kauai. Until an analysis with a larger data base is done, the 11% figure can be used as a rough approximation. This produces a return period of about 9 years for a tropical storm or hurricane.

In November 1955, an extra-tropical storm dropped twenty inches of rain on Kauai in 13.5 hours while a January 1956 storm dropped 40 inches in 30 hours. Hurricane Hiki, August 1950, had winds of 68 miles per hour on Kauai with 52 inches of rain falling in four days.

Topographic map of Oahu, Hawaii, showing contour lines, elevation points, and place names. The map includes labels for locations such as Manalei, Kilauea, Moeloa, Anahola, Kealahi, Kapaa, Wailua, Hanalei, Lihue, and Nawiliwili. Contour lines are marked with elevations like 100, 150, 200, 300, and 400. A scale bar at the bottom left indicates distances up to 10 miles.

FIGURE 2: ANNUAL RAINFALL VALUES WITH ISOLINES AND WEATHER STATION NUMBERS.

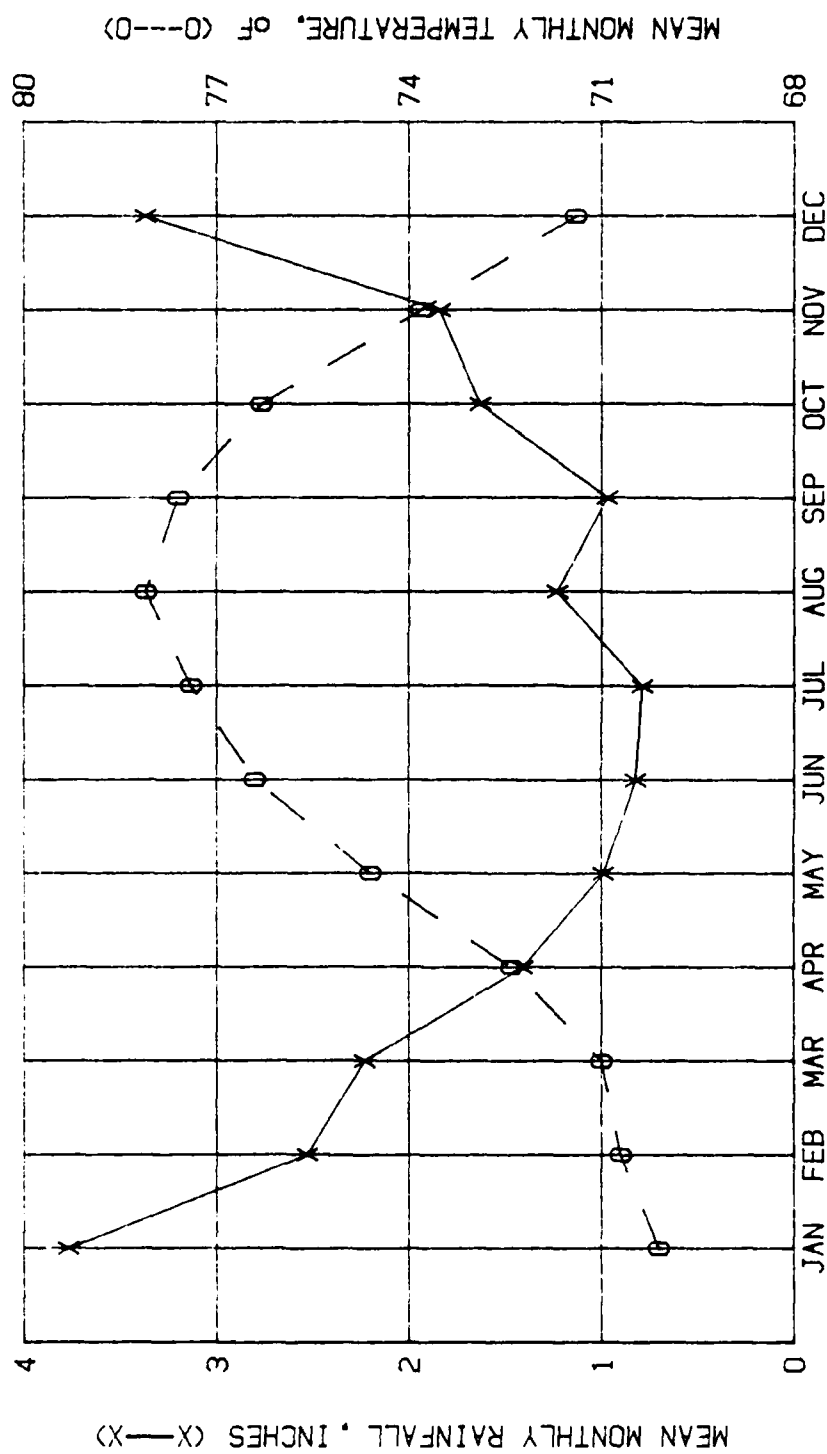


FIGURE 3: MONTHLY CLIMATIC TRENDS, MANA STATION, KAUAI, HAWAII

Hurricane Della, September 1957, passed a few hundred miles west of Kauai but caused heavy surf along the southern shores with waves 21 feet high and periods of 18.5 seconds (Corps of Engineers, 1969). Hurricane Nina, December 1957, produced winds of 90 mph, 20 inches of rain in 14 hours, and large waves along the south shore. Hurricane Iwa, November 1982, brought winds of up to 80 miles per hour but dropped only three inches of rain on Kauai while causing record dollar amounts of damage (National Research Council, 1983).

The tidal range is small. For nearby Waimea Bay (see Figure 1), Harris (1981) gives a mean tidal range of 1.0 feet and a mean spring range of 1.6 feet. Sea level rise is estimated to be only 0.005 feet per year, based on data collected at Honolulu since 1905 and presented in Hicks, Debaugh, and Hickman (1983).

### III. WIND DATA

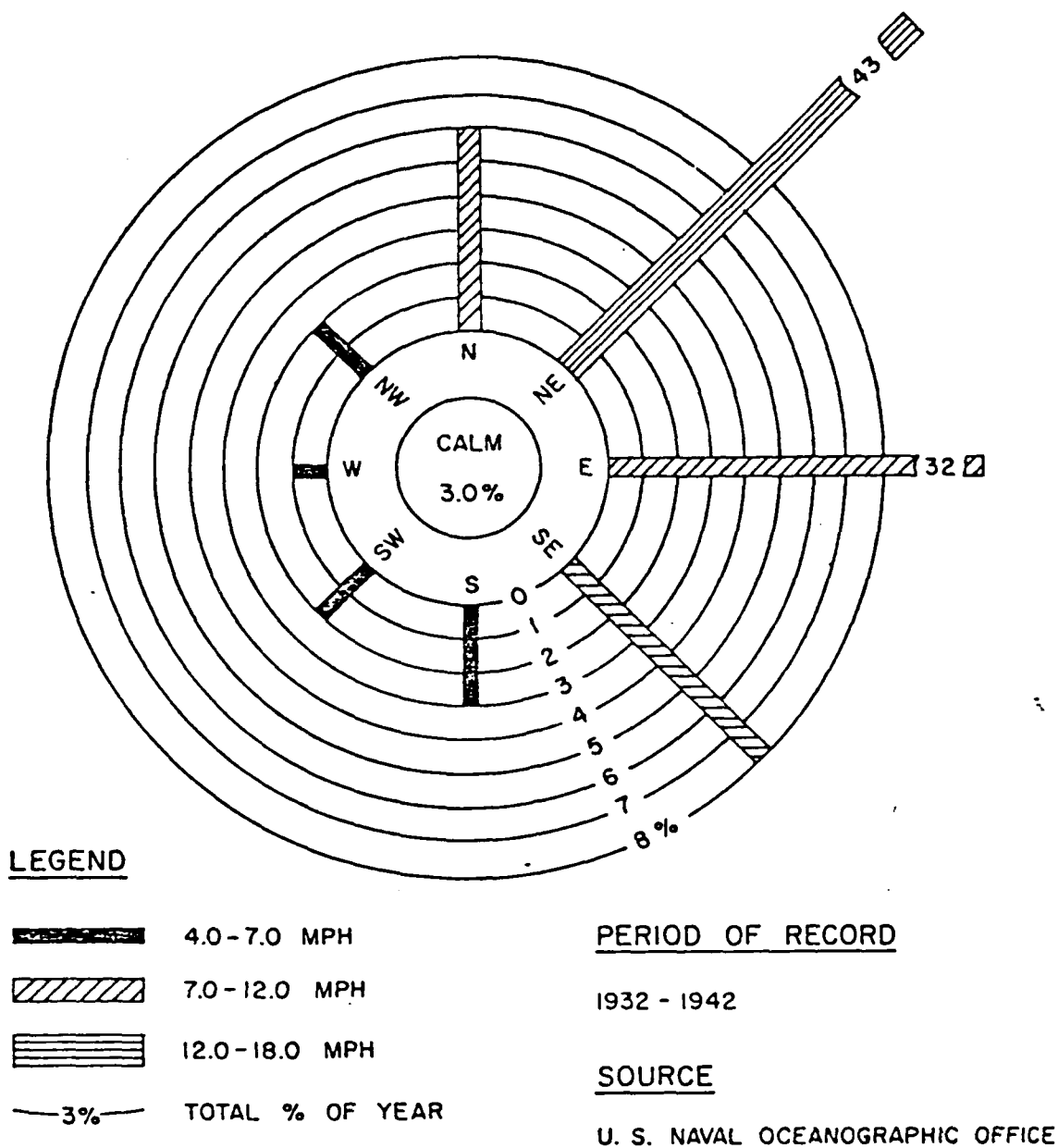
The winds of Kauai are dominated by the northeast trades with different patterns evident during the two meteorological seasons. The summer months of April through November are a time of strong northeast trade winds. Winter brings a weakening of the trade winds and the appearance of southeasterly winds and fronts from the north temperate zone. Winter is also the most likely time for the so-called Kona weather, which is characterized by intense winds and waves from the southwest due to local fronts or Hawaiian lows of extra-tropical origin (Marine Advisers, 1964). During the summer, 80% to 90% of the winds are due to the trade winds. During the winter, the percentage drops to 50% to 80% (Corps of Engineers, 1978).

Figure 4 from Corps of Engineers (1966) presents the yearly average of offshore wind data as collected over a ten-year period from marine deck observations. The predominance of the northeast trade winds is striking; winds are from the northeast and east 75% of the time.

Nearshore winds on the other hand have quite a different distribution. Figure 5 shows wind data collected at the PMRF meteorological station during the years 1966 to 1972. The percentage of winds from the northeast and east have been significantly reduced due to the local topography. The PMRF is located on the western side of the island of Kauai which has mountainous terrain dominated by Mt. Waialeale with an elevation of 5080 feet. The coastal plain, on which the PMRF beach is the seaward edge, lies directly at the base of large coastal cliffs. Therefore, the PMRF is significantly sheltered from the northeast trade winds. Figure 5 shows that the strongest winds come from the north but the largest percentage are from the west. Fifty percent of all wind observations are from the west to north quadrant.

Study of the monthly wind roses, Figures 6a through 6l, shows the predominance of westerly winds during the summer months, and northerly to northwesterly winds during the winter months. Also, during the winter months, significant winds come from the south to southeast.

With regard to design winds, the American National Standards Institute presents a 50-year wind of 80 mph (ANSI, 1982). National Research Council (1983) studied the effects of Hurricane Iwa and presented Figure 7 to show the recorded wind speeds on Kauai. Note that the winds do not exceed the 50-year wind. National Research Council (1983) concluded that Iwa was not a major storm.



**OFF-SHORE WIND DIAGRAM**  
(YEARLY AVERAGE)  
BARKING SANDS

(from Corps of Engineers, 1966)

FIGURE 4: OFFSHORE WIND DATA

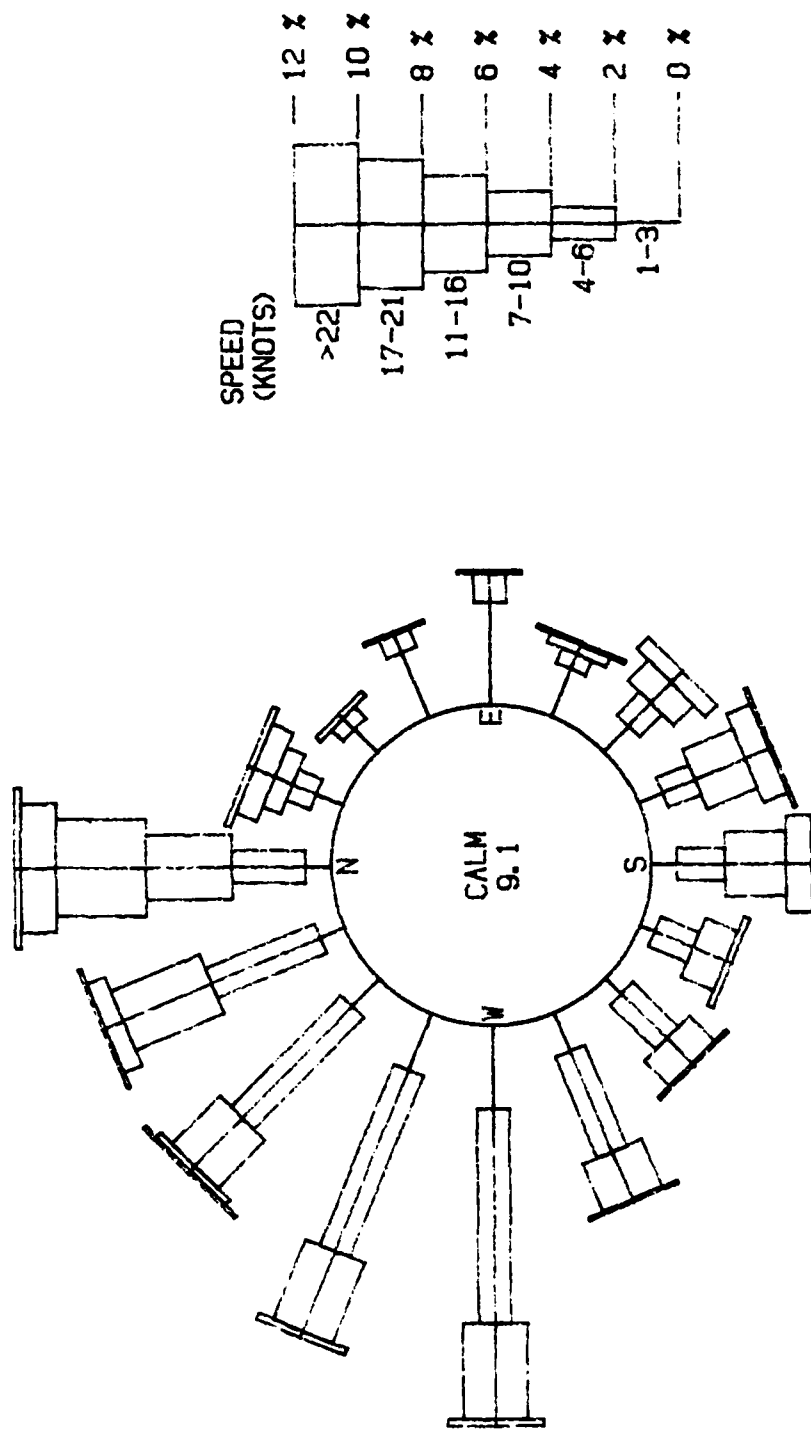


FIGURE 5: WIND ROSE, BARKING SANDS, ALL MONTHS, 1966-1972



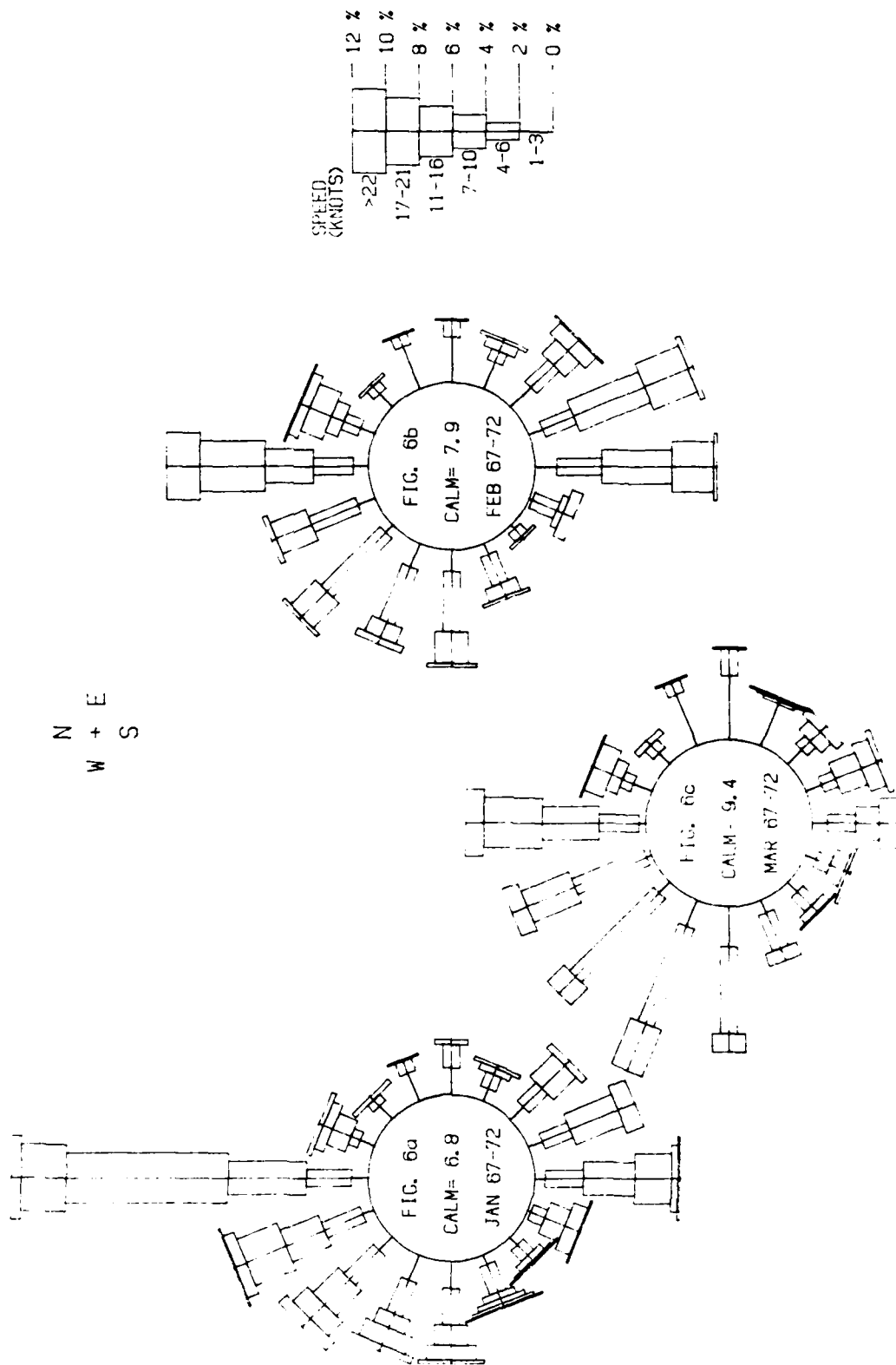


FIG. 6: WIND ROSE, BARKING SANDS.

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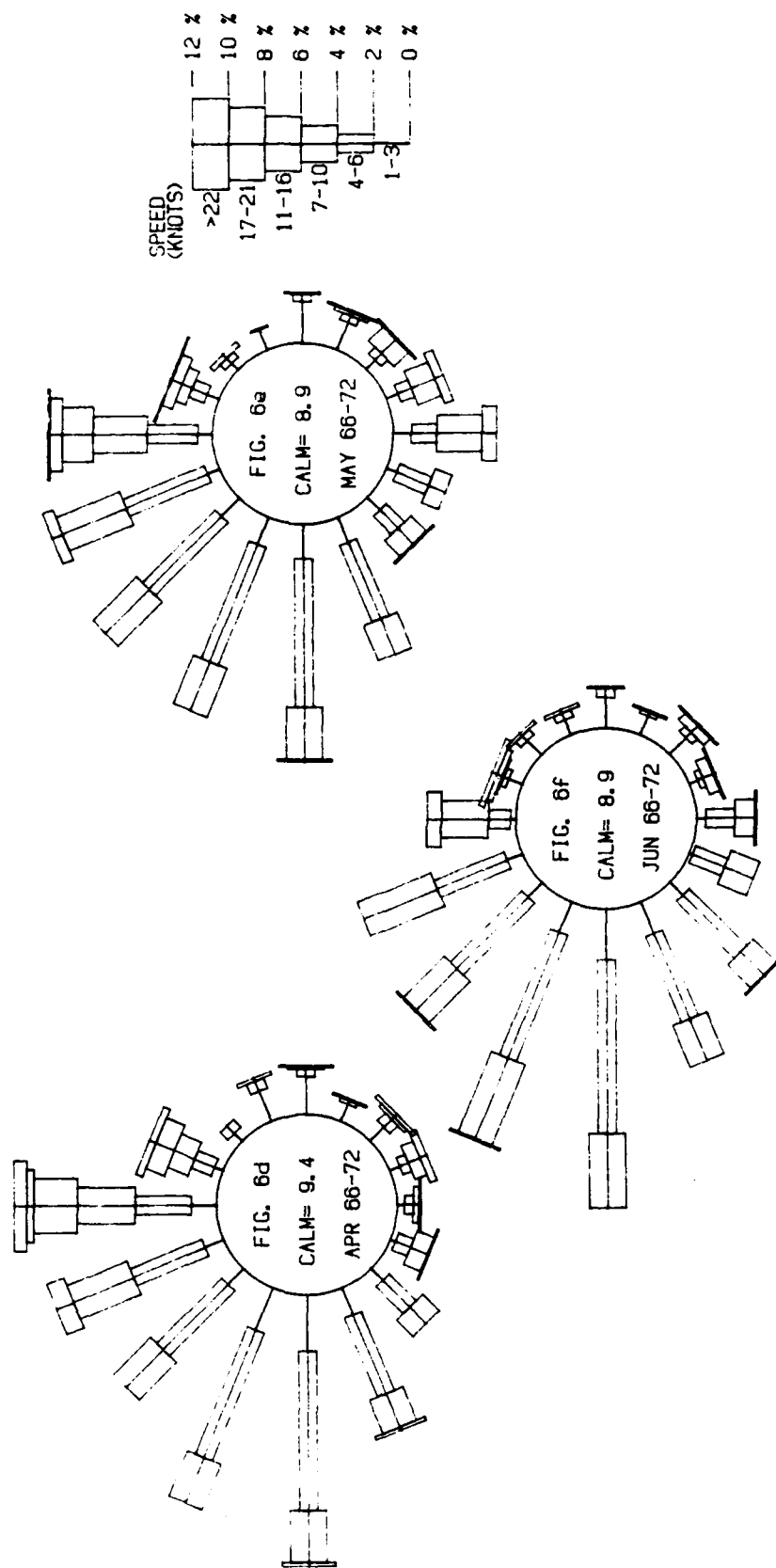


FIG. 6: WIND ROSE, BARKING SANDS.

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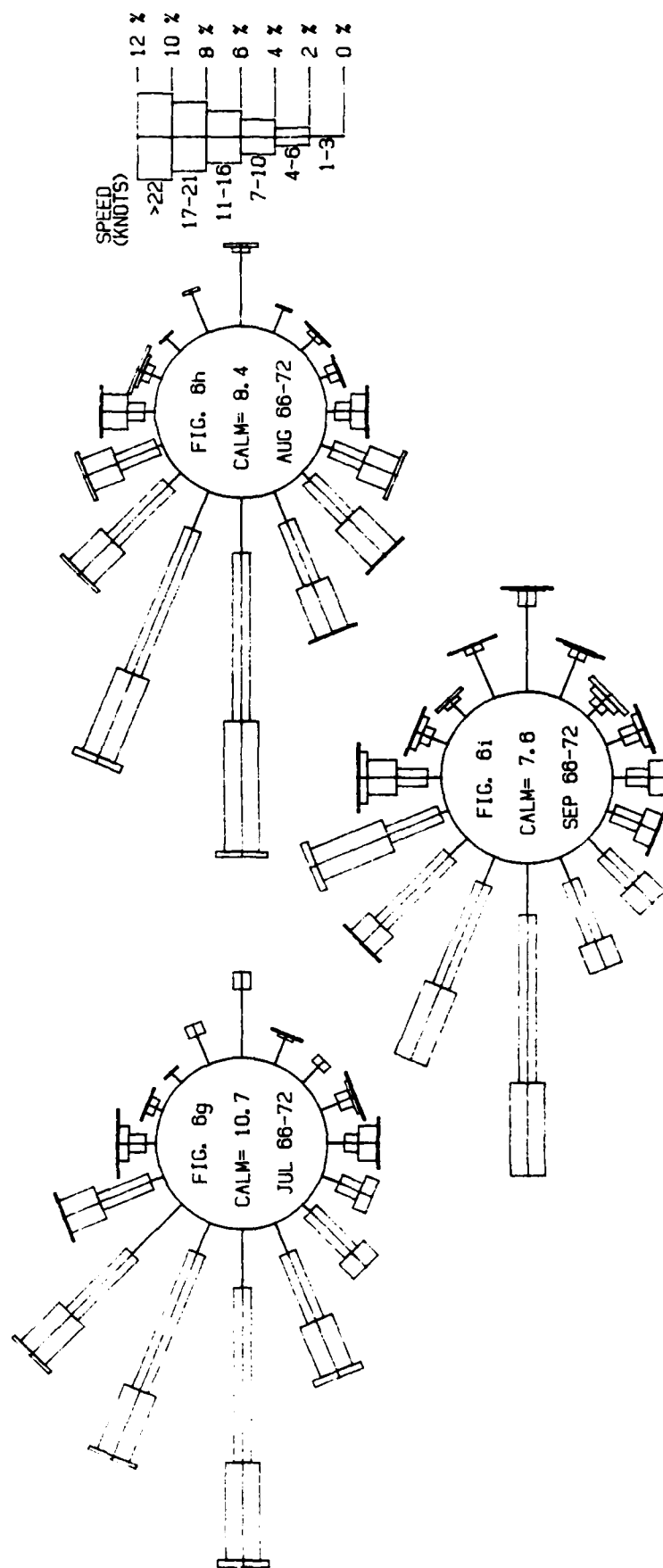


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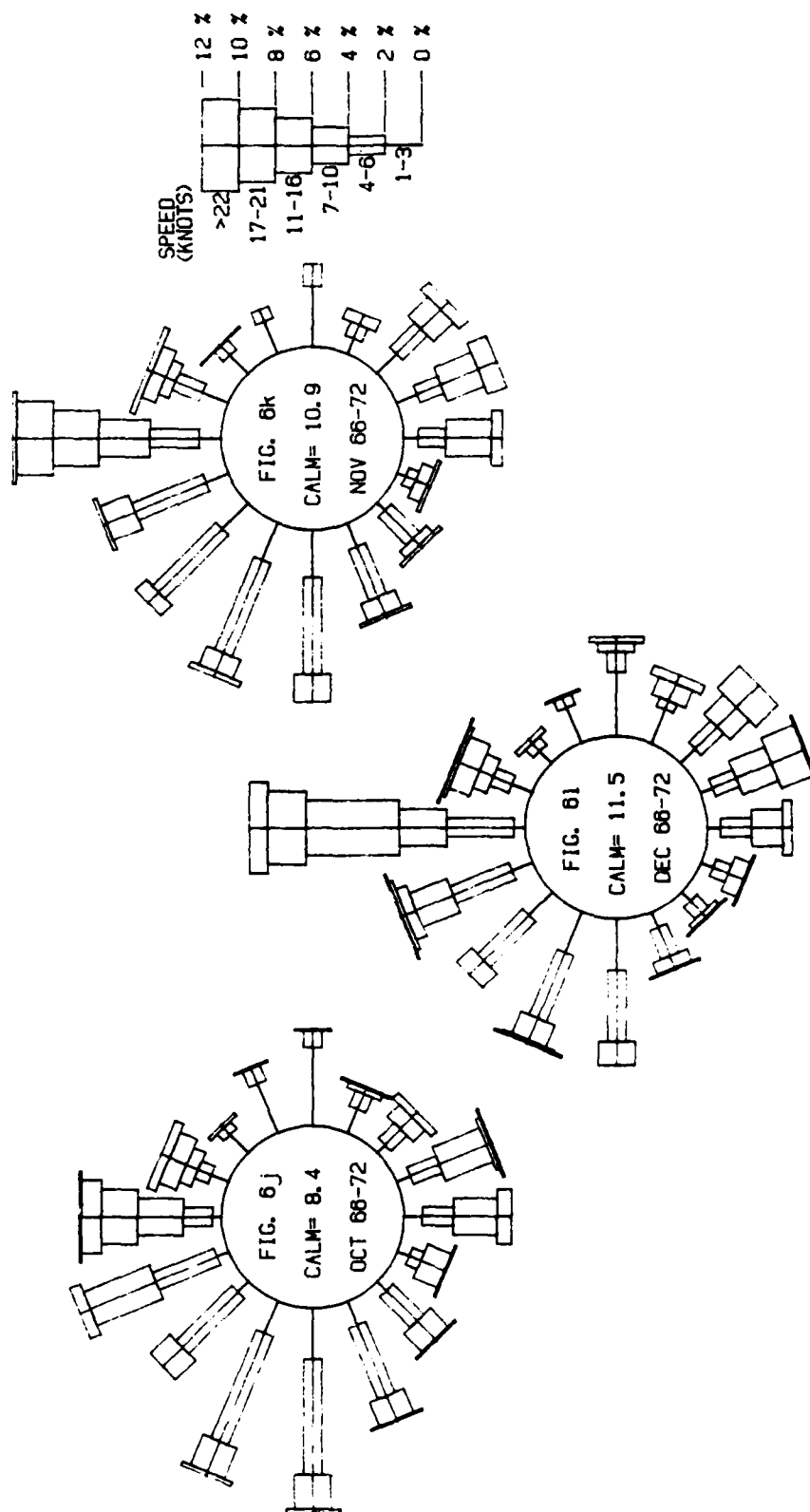
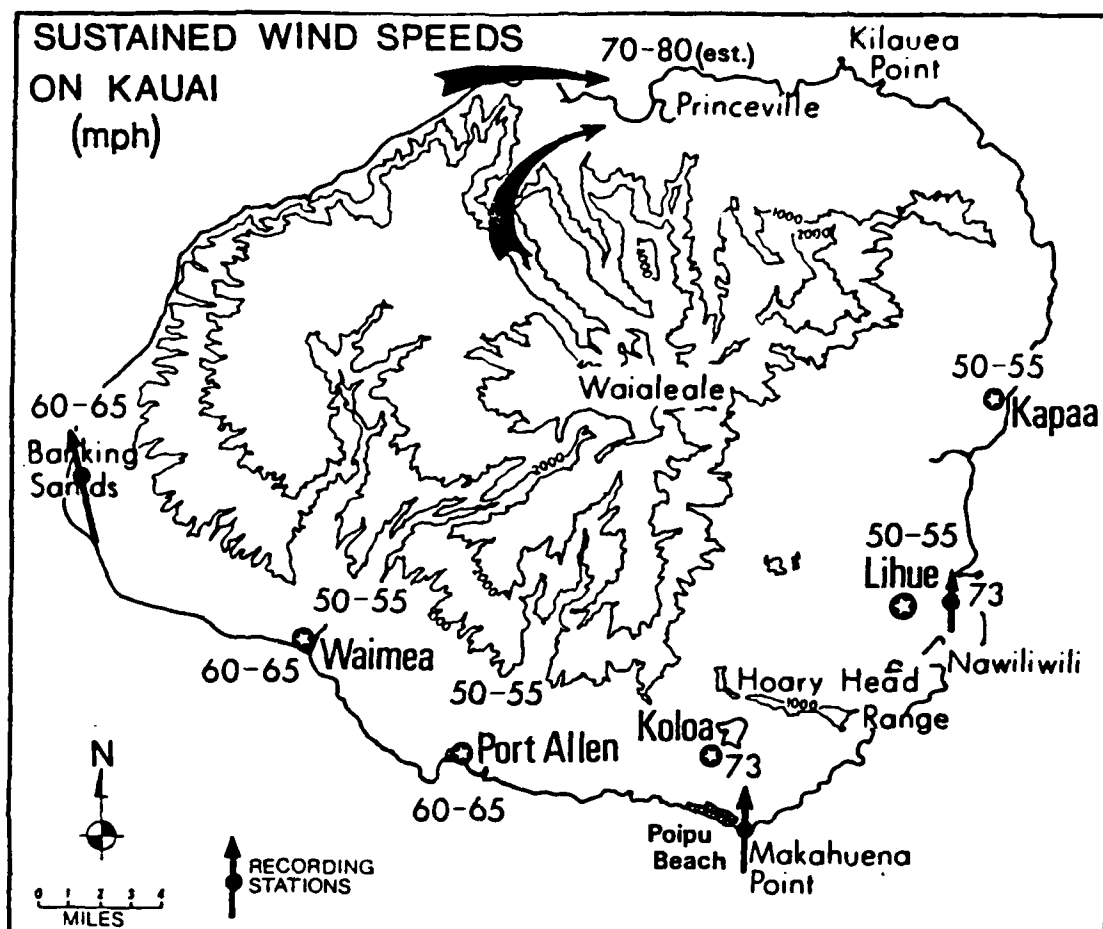


FIG. 6: WIND ROSE. BARKING SANDS.



(from National Research Council, 1983)

FIGURE 7: HURRICANE IWA WIND VELOCITIES.

#### IV. WAVE DATA

##### A. Wave Types.

The Hawaiian islands are regularly subjected to four types of wind waves or swell: northeast trade waves, southern swell, Kona storm waves, and North Pacific swell. Figure 8, from Chamberlain (1968), shows the range of approaches of these waves. The following summary is based on information found in Inman, Gayman, and Cox (1963) and Marine Advisers (1964).

The northeast trade waves are generated by the prevailing northeast trade winds. They occur throughout the year but are most intense during the summer months of April through November, when they are present 90% to 95% of the time. During winter, the percentage drops to 55% to 65% of the time. Wave heights range from 4 to 12 feet and periods from 5 to 8 seconds. The approach is from the north to east. These waves reach the PMRF site by refracting and diffracting around the northwestern and southwestern sides of Kauai.

Southern swell are generated near Australia, Antarctica, and the southern Indian Ocean during the winter months of the Southern Hemisphere, which are the summer months of April through November at Kauai. The waves are long and low, with heights of only 1 to 4 feet but periods of 14 to 22 seconds. Their approach is from the southeast to southwest.

Kona storm waves are generated by intense winds due to local fronts or Hawaiian lows usually during the winter. The waves are 10 to 15 feet high with periods of 8 to 10 seconds. The direction of approach is from the southeast to west with the largest waves coming from the southwest. Kona waves occur infrequently, only 9% of the time in a typical year, but their intensity makes them a significant factor in the coastal processes of Kauai.

North Pacific swell are products of storms in the Aleutians and of mid-latitude lows. They occur throughout the year but are most intense and numerous during the winter months of October through May. Wave heights are 8 to 14 feet with periods of 10 to 17 seconds. The direction of approach ranges from northwest to northeast. North Pacific swell are some of the largest waves which reach Kauai.

Figure 9 and Table 1, from Corps of Engineers (1966), present information covering the years 1955 to 1963 on storms which have affected the PMRF study area. Wave heights near the shoreline will be limited by the depth of water at the location of interest.

Kauai is subject to tsunamis seismically generated primarily in the Kamchatka - Kurile Islands - Aleutian Islands area in the Northern Hemisphere, and secondarily off the coast of Chile in the Southern

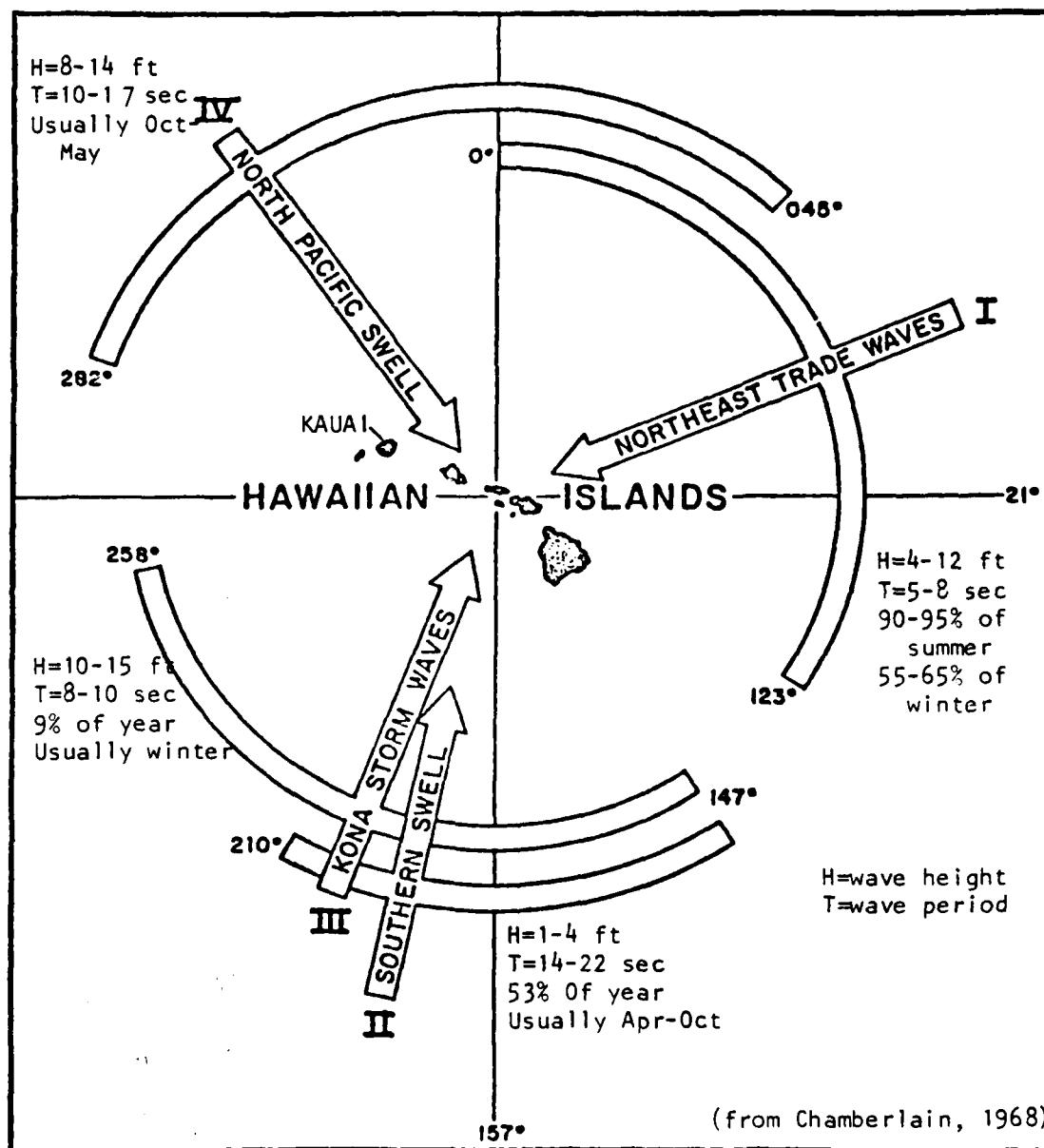


FIGURE 8: HAWAIIAN WAVE TYPES.

TABLE 1: Deepwater Storm Data

Storm	Wind Speed (knots)	Fetch Length (naut mi)	Decay Distance (naut mi)	Minimum Duration (hours)	Deep Water Wave Height	Period (seconds)	Deep Water Wave Length (feet)	Direction
21 Dec 55	23	1,660	0	40	12.0	11.0	620	S 75° W
26 Nov 56	29	1,170	490	38	9.0	14.9	1,137	N 30° W
4 Sep 57 <sup>1/</sup>	78	140	190	8	21.0	18.5	1,751	S 78° W
13 Jan 58	40	2,000	430	80	27.6	21.5	2,366	N 55° W
18 Jan 59	22	730	0	57	12.0	11.6	689	S 67° W
19 Dec 60	31	1,610	50	38	17.4	13.7	961	N 28° W
8 Jan 62	27	1,800	0	48	16.6	12.8	839	N 40° W
17 Jan 63	30	1,320	0	73	22.0	15.3	1,199	N 45° W

<sup>1/</sup> Hurricane

(from Corps of Engineers, 1966)

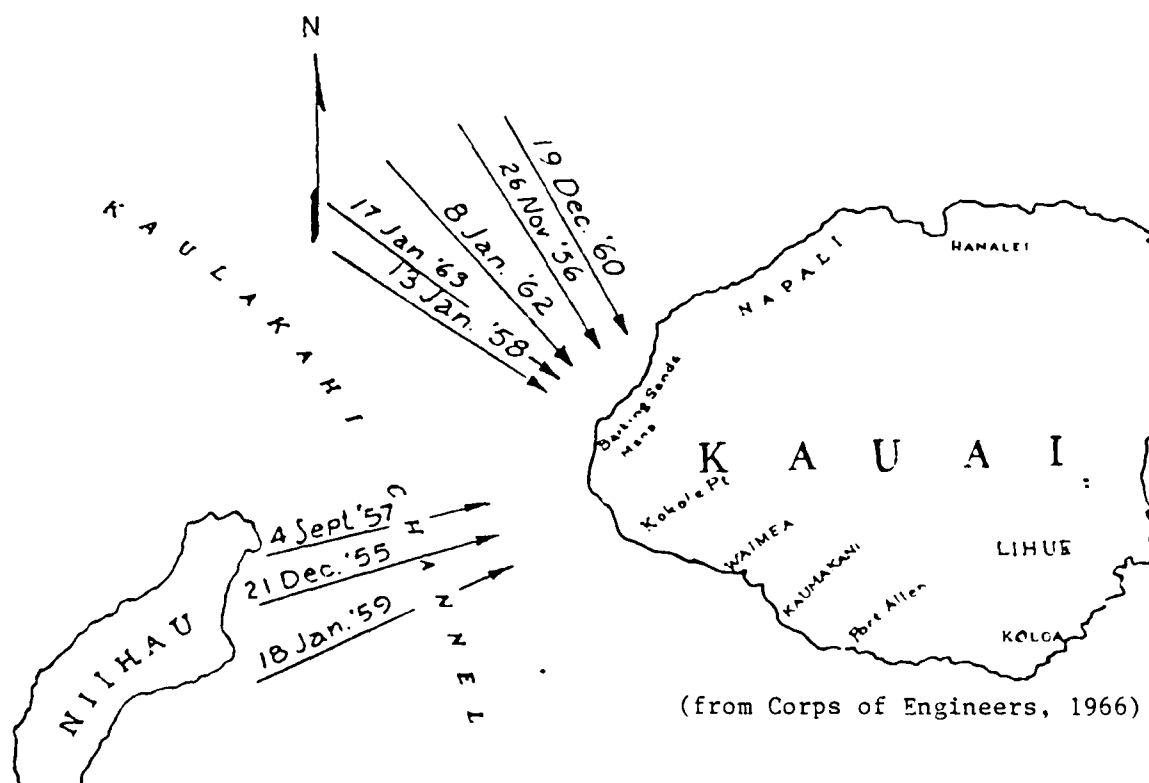


FIGURE 9: DEEPWATER STORM DIRECTIONS TOWARDS PMRF.



Hemisphere. Tsunamis have historically caused considerable erosion and can move large chunks of coral reef material. Corps of Engineers (1966) reports 41 damaging tsunamis in the Hawaiian Islands in the 146 previous years. Of these, 7 were very severe, 2 severe, 8 moderate, and 24 slight. The 1 April 1946 tsunami from the Aleutian Islands caused waves of 17 feet at Mana Point, 24 feet at Nohili Point, and 33 to 38 feet near Polihale. The 23 May 1960 tsunami from offshore Chile caused high water marks of 8 feet near Mana Point. More recent summaries of tsunamis were not found.

#### B. Wave Data.

Marine Advisers (1964): The most complete set of deepwater wave data now available in the Kauai area is in Marine Advisers (1964). The report was done for the island of Oahu but is applicable to Kauai since it is deepwater data and the effects of land masses were neglected. The data were not averaged over a number of years; rather, many years were studied to identify a "typical year" and then the data from that year is presented. However, a full "typical year" was not found, so a composite "typical year" was put together. The summer of the composite year consisted of July through November of 1962 and April through June of 1963. The winter months included December 1952 and January through March 1951.

The waves for the summer months consisted of Northern Hemisphere swell and Southern Hemisphere swell. The winter months included Northern Hemisphere swell and waves. Kona waves were added in where appropriate. The data itself is a combination of visual observations, wave hindcasting, and wave gage data.

Figure 10a is the annual wave rose for the Marine Advisers data. The predominant directions of wave approach are from the northwest, the east-northeast, the east, the south, and the south-southwest. However, separating the data into its winter and summer components presents a better picture of what can be expected during a certain time of year.

Figure 10b shows the wave rose for the winter months. The effects of the northeasterly trade winds and the North Pacific swell are easily seen. Also, the large Kona waves from the south-southeast to the west-southwest are shown.

The summer waves rose is plotted in Figure 10c. Again, the northeast trade waves are present but the North Pacific swell is diminished. The summer swell from the Southern Hemisphere appear from the south to south-southwest and are generally of low wave height.

PMRF Visual Observations: Beginning in July 1968, twice-daily visual observations of surf conditions were made by PMRF personnel as part of their routine weather data collection. The data collected were significant wave height, maximum breaker wave height, wave period,

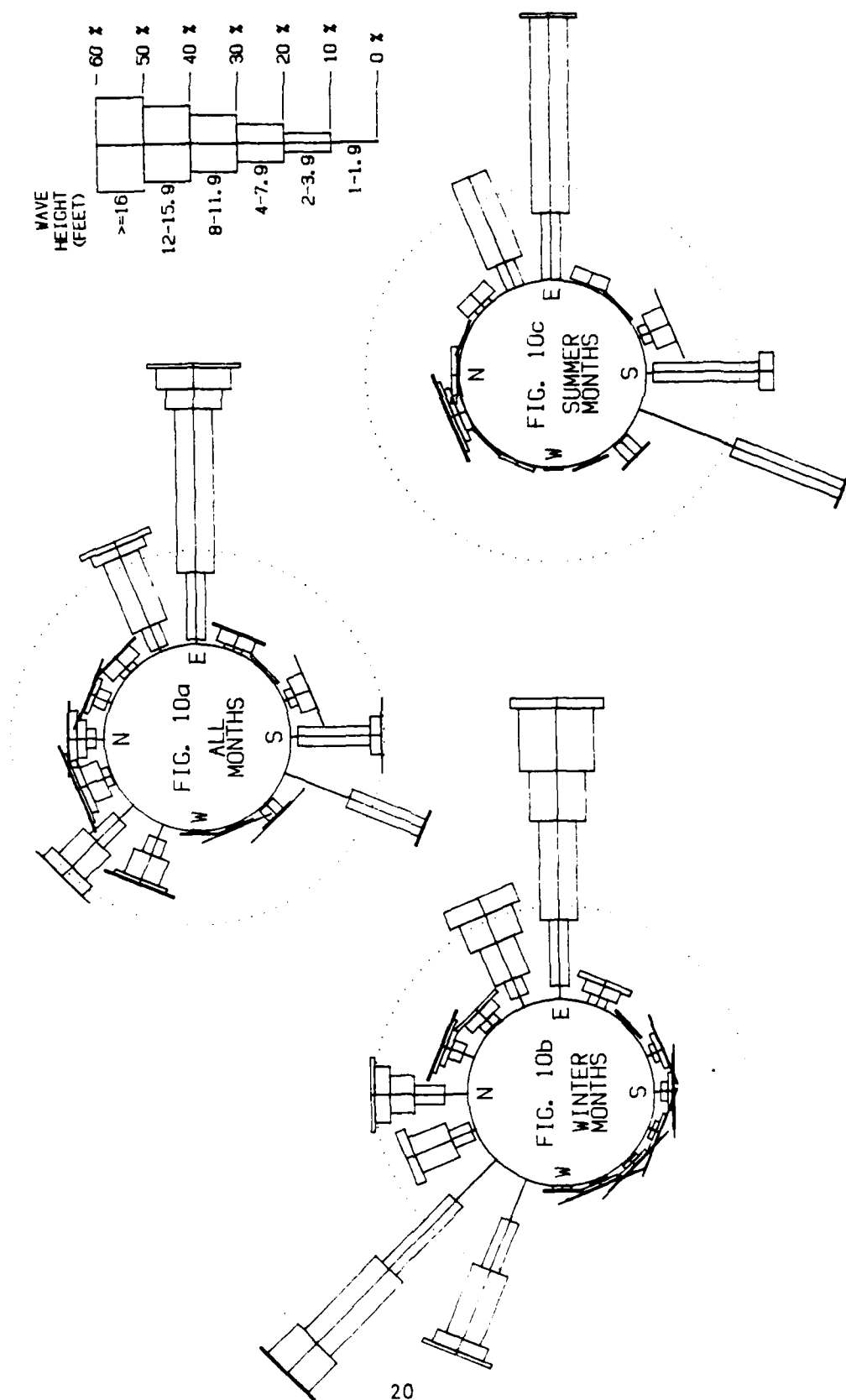


FIGURE 10: DEEPWATER WAVE ROSE, MARINE ADVISERS (1964)

percent plunging and spilling waves, and the angle of wave approach to the shoreline. The most useful data are the significant wave height and the wave period. The former is discussed below. Although the wave angle was estimated with each observation, most of the recorded values were zero. Therefore, the wave angle data will not be analyzed in this report.

The accuracy of visual observations of wave height is low. However, the fact that fifteen years of data are available and have been averaged together should justify confidence in the data as a credible description of the general wave environment in the surf zone. The data are grouped by month.

Figure 11 shows the distribution of wave heights as a fraction of all waves observed. For example, during January almost 25% of the waves were approximately four feet high. The more spread there is in the distribution, the more variation there is in the observed waves. The summer months of April through September show distributions concentrated more to the low wave height end of the abscissas than the winter months of October through March. The months of June, July, and August are particularly mild with most waves being two feet or less.

The same monthly variation can be illustrated by plotting wave heights in cumulative form. Figure 12 shows the cumulative fraction of waves observed which were less than or equal to the wave height on the abscissa. The more the cumulative line tilts toward the right as it moves up, the higher the wave climate. Again, the difference between the October through March winter months and the April through September summer months is obvious.

The monthly variations over the year are compactly shown in Figure 13.  $H_{10}$  is the wave height that 10% of the observed waves were greater than. Similar definitions apply to  $H_{50}$  and  $H_{90}$ .  $H_{max}$  is the maximum wave height observed.  $H_{50}$  is also known as the median wave height. The data plotted in Figure 13 are listed in Table 2. The milder wave climate during the summer is evident.

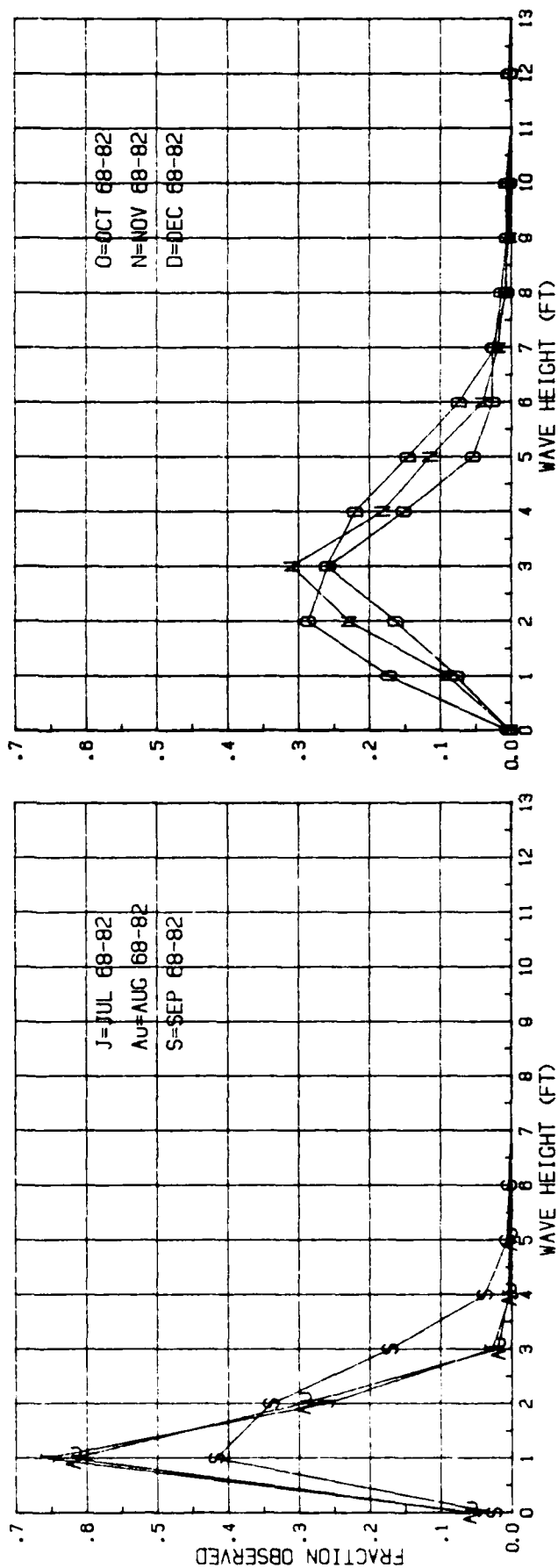
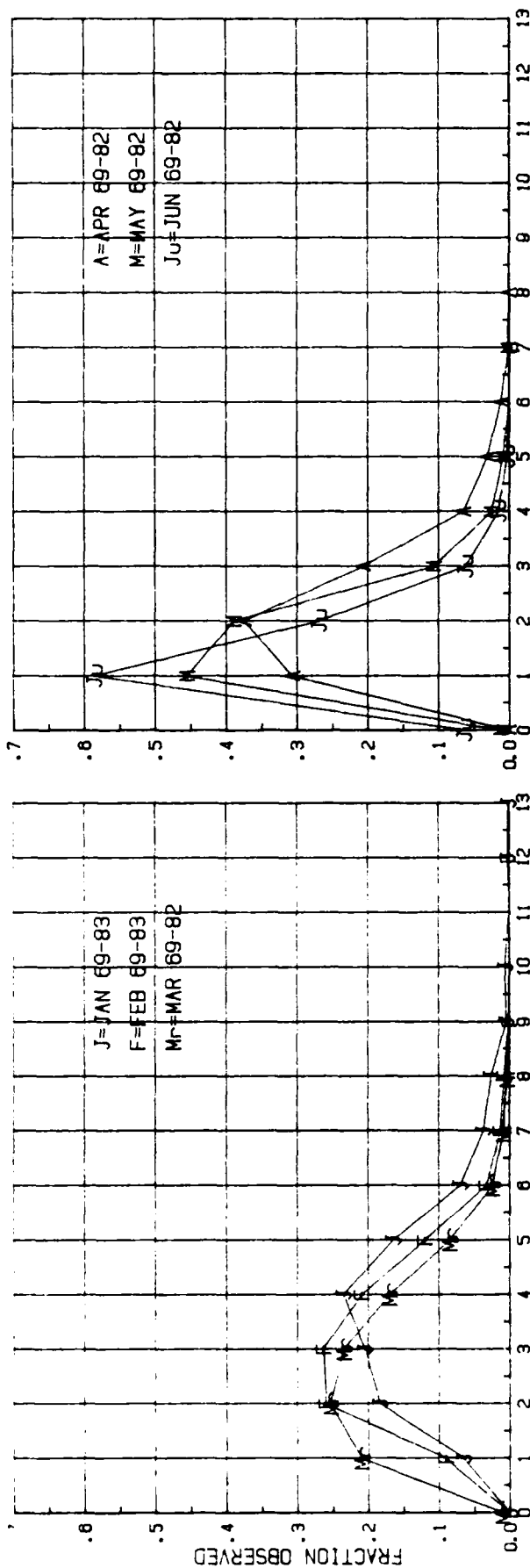


FIGURE 11: WAVE HEIGHT DISTRIBUTION, VISUAL BEACH OBSERVATIONS.

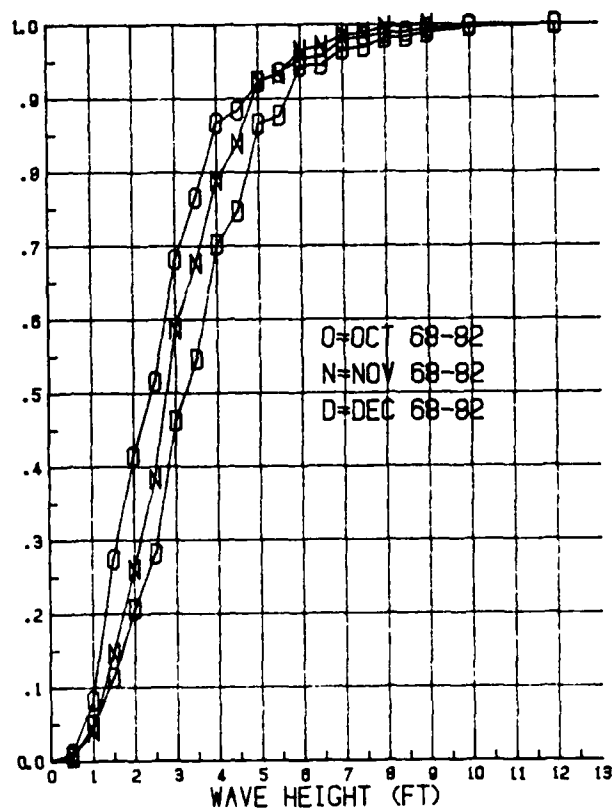
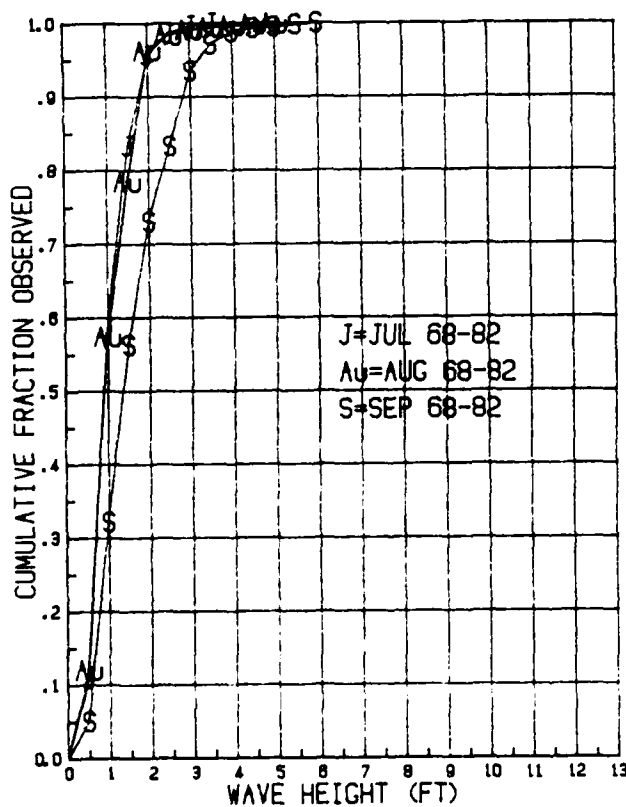
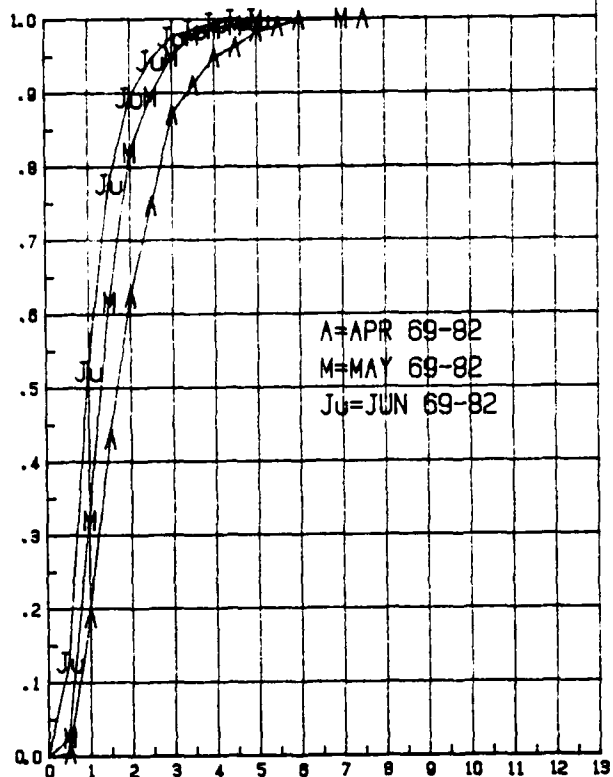
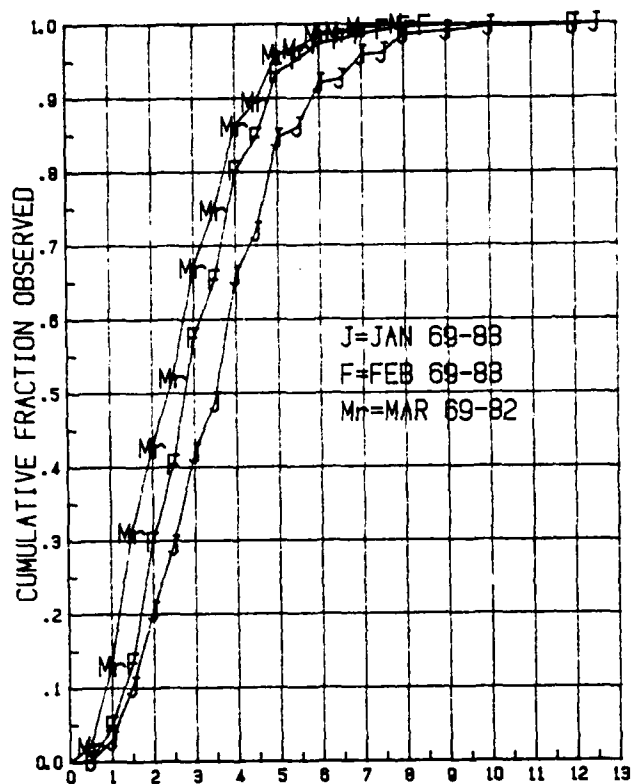


FIGURE 12: WAVE HEIGHT CUMULATIVE DISTRIBUTION, VISUAL BEACH OBSERVATIONS

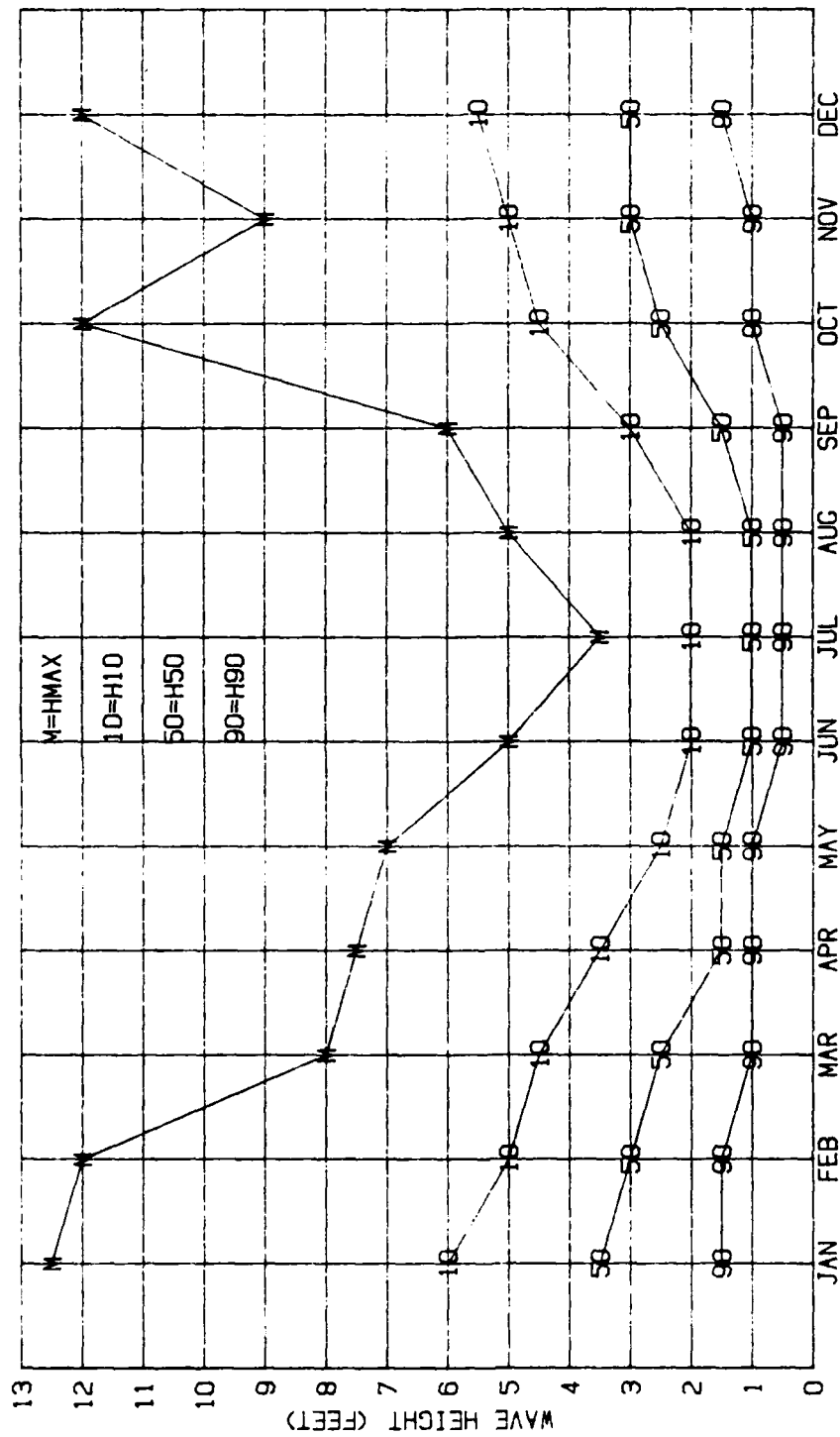


FIGURE 13: MONTHLY WAVE CLIMATE, PMRF VISUAL OBSERVATION 1968-83

Table 2: Monthly Wave Height Cumulative Values (feet).

MONTH	H <sub>90</sub>	H <sub>50</sub>	H <sub>10</sub>	H <sub>max</sub>
JAN	1.5	3.5	6.0	12.5
FEB	1.5	3.0	5.0	12.0
MAR	1.0	2.5	4.5	8.0
APR	1.0	1.5	3.5	7.5
MAY	1.0	1.5	2.5	7.0
JUN	0.5	1.0	2.0	5.0
JUL	0.5	1.0	2.0	3.5
AUG	0.5	1.0	2.0	5.0
SEP	0.5	1.5	3.0	6.0
OCT	1.0	2.5	4.5	12.0
NOV	1.0	3.0	5.0	9.0
DEC	1.5	3.0	5.5	12.0

## V. GEOLOGY

### A. The Island.

As described in Macdonald, Davis, and Cox (1960), the island of Kauai and the adjacent island of Niihau are lava domes located at the top of one large marine volcanic mountain. Since neither has been volcanically active for quite a while, the islands are considerably weathered. Kauai has been dissected by several streams which have carved valleys into the landscape, Figure 14. The most spectacular is the Waimea Canyon, produced by the Waimea River, which empties into the Pacific a short distance southeast of the study site. The coastal cliffs, 300 to 1200 feet high, which outline much of the island were cut by the pounding of the ocean waves over many years.

### B. The Mana Plain.

The study area is located near the seaward edge of the Mana Plain, which has formed at the western side of the island. The Mana Plain is made up of lagoonal deposits and alluvium from the uplands and calcareous beach and dune sands which lie atop Waimea Canyon volcanic series lava flows (Macdonald, Davis, and Cox, 1960). The plain was swamp land until artificially drained (Emery and Cox, 1956).

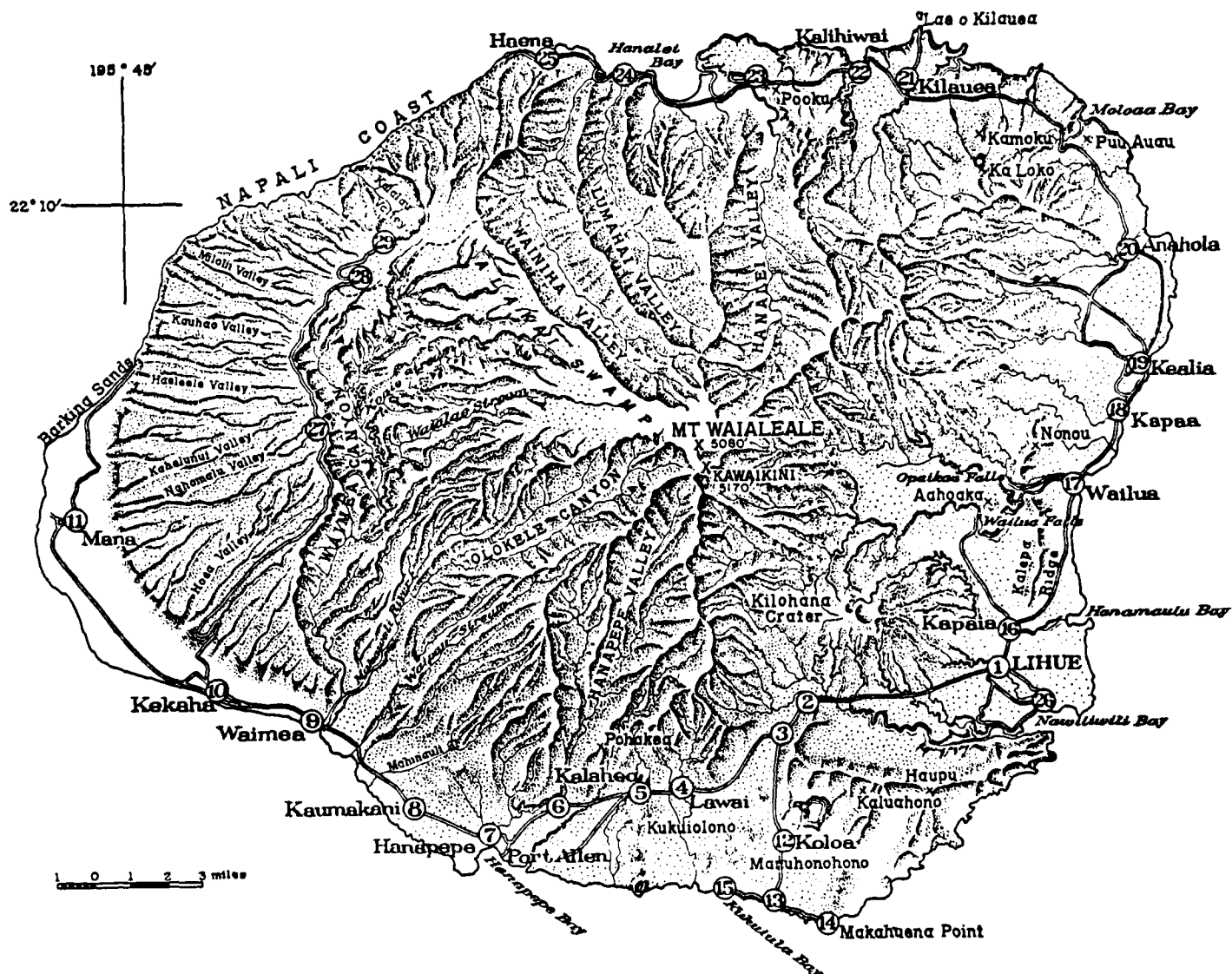
### C. Beach Sand.

According to Inman, Gayman, and Cox (1963), the beach sand of the study area is of medium size, less well-sorted than typically found on continental U.S. beaches, and has a high carbonate content. For the two samples taken by Inman, Gayman, and Cox which were closest to the PMRF site,  $D_{50}$  was 0.71 and 0.78 mm. The percent carbonate was 85% and 90%, which demonstrates the predominance of the biological contribution as a sand source. Four sand samples from the PMRF cable landing area were collected and analyzed by CHESNAVFACENGCOM. The values of  $D_{50}$  were found to be 0.60 mm, 0.63 mm, 0.59 mm, and 0.62 mm. Figure 15 from Hirata & Associates (1983) shows the size distribution of a sand sample from the cable landing site. As demonstrated in the figure, the sand is poorly sorted with a  $D_{50}$  of approximately 0.52 mm.

The primary source of sand is the marine life in the area which produce calcareous sediments that are moved onshore by the waves. The secondary source is the Waimea River which carries sand-size materials into the ocean from the uplands of the island. The Waimea River contributions are significant only on the beaches near the river mouth.

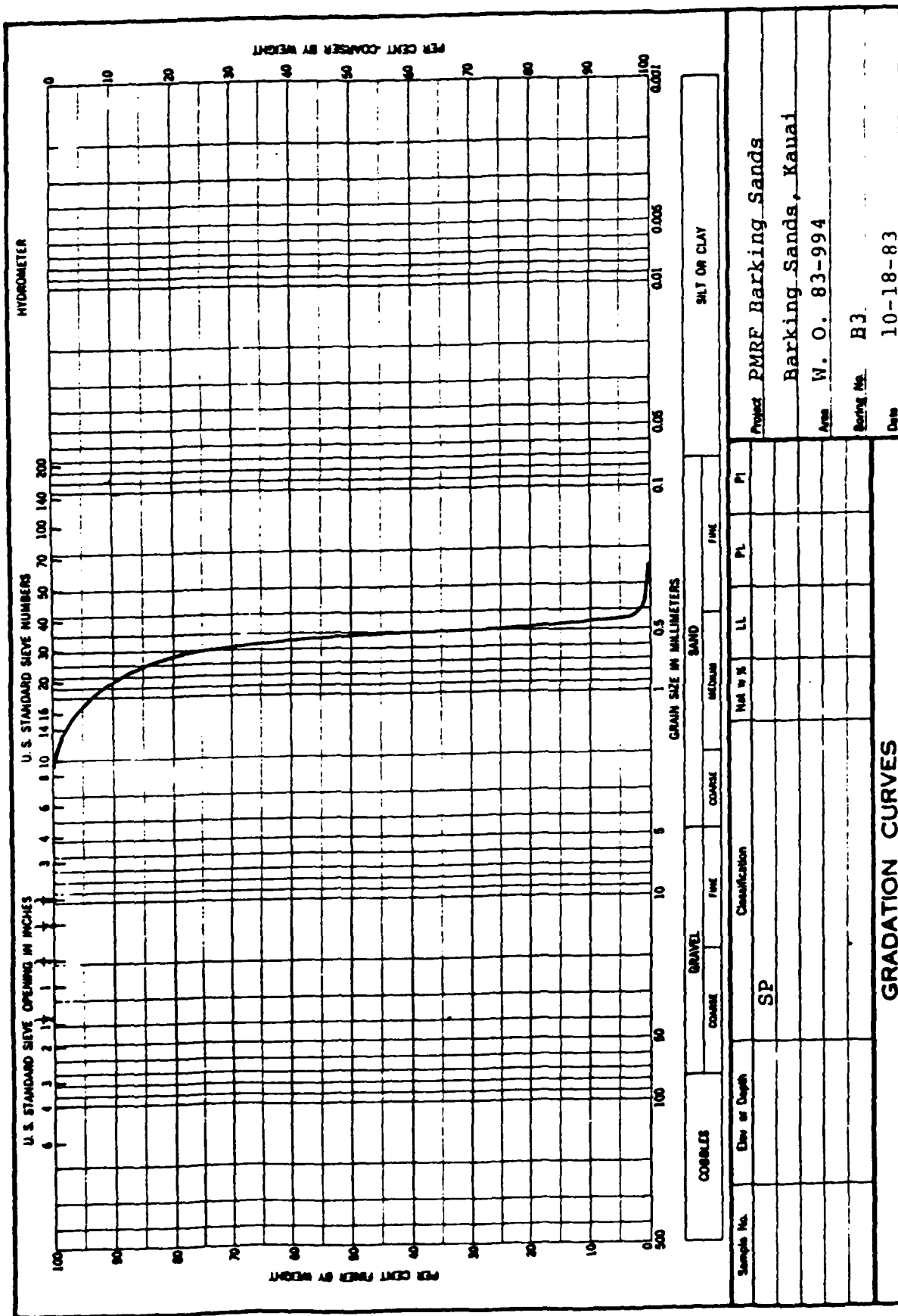
Observers familiar with the PMRF site describe the beach as sand-covered during the summer months and exposed beachrock during the winter months. In order to get a more quantitative description, a procedure to collect beach sand depth was recently begun. In June 1983, a pipe was installed into the beachrock near the site of the cable landings. The pipe extends vertically six feet out of the beachrock. On a daily basis, the level of the beach sand on the pipe





(from Macdonald et al., 1960)

FIGURE 14: GEOLOGIC FEATURES OF KAUAI, HAWAII



SDS FORM 2017 REPLACES SDS FORM NO. 1241, SEP 1963, WHICH IS OBSOLETE. (TRANSLUCENT) c 3430  
 (from Hirata & Associates, 1983)

FIGURE 15: SAND SIZE DISTRIBUTION.

is measured. Figure 16 shows the variation in sand depth at the pipe up to February 1984. Manifested by the figure is the episodic nature of both the erosion and accretion processes, particularly the former. Also, the transition from summer to winter sand thickness is clearly shown. Future work will entail correlating this sand level data with the local wave climate.

D. Beachrock.

Emery and Cox (1956) define beachrock as a stratified calcareous sandstone (calcareenite) or conglomerate (calcirudite) occurring along many beaches that are composed of shells or other calcareous debris. It is common on beaches of islands with coral reefs. Beachrock is very evident at the PMRF site and has provided a challenge to the engineers trying to protect the cables which run onshore over the rock.

A number of causes of beachrock formation have been suggested. It could be due to the evaporation of interstitial seawater which leaves calcium carbonate to cement the sand particles. It could be due to groundwater which first passes through limestone, where it picks up calcium carbonate, and then passes through the sand beach, where it leaves the calcium carbonate as the water evaporates. Or it could be due to the mixing of sea water and groundwater which causes calcium carbonate to precipitate out. Chamberlain (1965) suggests that the beachrock in the study area is due to the second method, that is, the evaporation of calcium carbonate-laden ground water.

A cable that is brought onshore and laid on top of a sandy beach will be buried in the sand by the swash action of the waves. When storms occur and cause erosion of the beach, the sand on top of the cable is moved offshore. The process of cable burial then repeats and the cable is buried at progressively deeper depths, thereby remaining protected. The presence of beachrock at depths uncovered by storms will interrupt this process and expose the cable to wave damage. Therefore, a location where there is no beachrock, or where the beachrock is very deep, is a good place to bring cables ashore.

Emery and Cox (1956) reports on an expedition to the Hawaiian Islands to survey the extent of beachrock. Figure 17 shows where beachrock was found, and where it was not found, on Kauai. Note that the largest extent of beachrock on Kauai is at Nohili Point which is where the PMRF cables come ashore. Corps of Engineers (1966) reports visual observations during July 1966 showing bare beachrock from Nohili Point to about 1.5 miles southeast of Mana Point. Immediately northeast of Nohili is a large stretch of beach where no beachrock was found. Since this area is still close to the PMRF site, it might be a good place to bring cables ashore. The absence of beachrock will allow the cables to be buried in the sand.

The shore-normal and vertical extent of the beachrock was studied

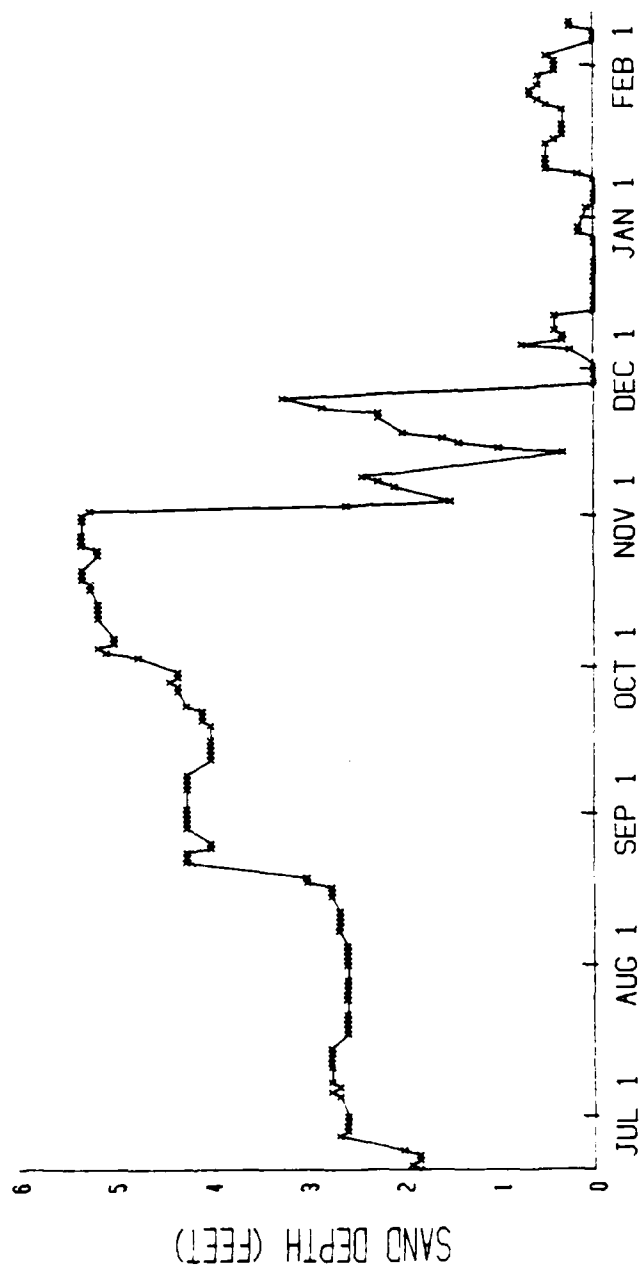
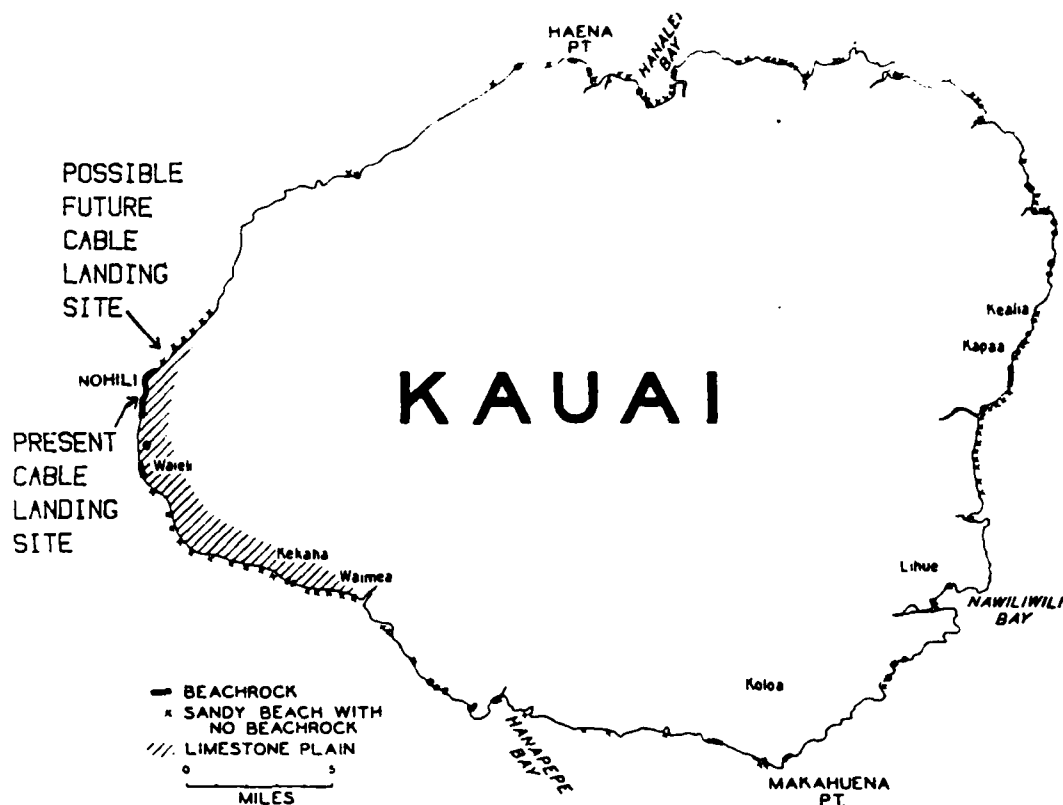


FIGURE 16: SAND DEPTH ABOVE BEACHROCK AT PMRF PIPE (JUN 83 -FEB 84 )

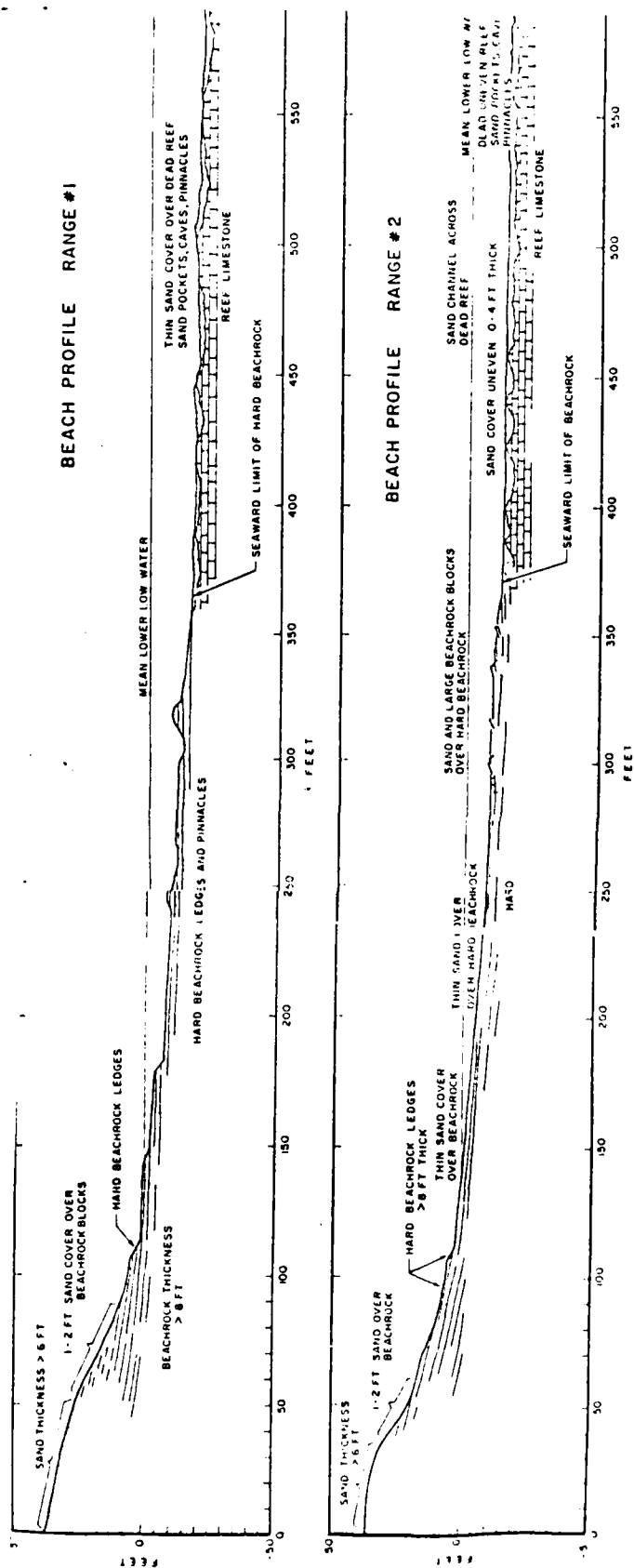


(from Emery and Cox, 1956)

FIGURE 17: BEACHROCK LOCATIONS ON KAUAI.

by Chamberlain (1965). Two profile lines were run offshore from the PMRF site. Along the profile lines, the bottom was identified and sampled. Figure 18 shows the results. Most significant is the wide extent of the beachrock which runs from 100 feet shoreward to about 200 feet seaward of the waterline. The sand layer which periodically covers the beachrock on shore is also shown. The thickness of the beachrock is noted as being at least 8 feet thick since that is as deep as was checked.

In order to better define the beachrock at the PMRF cable landing area, CHESNAVFACENGCOM and PACNAVFACENGCOM developed and contracted a geotechnical study of the site. The primary task was the collection of three 30-foot borings on the beach which would extend through the sand and beachrock. The results of the study are presented in Hirata & Associates (1983). The locations of the three borings are shown in Figure 19. The depth of beachrock at Borings B1, B2, and B3 are 7.5 feet, 8.0 feet, and 14.5 feet, respectively. The maximum compressive strength found at each site was 3,470 psi, 3,120 psi, and 11,120 psi at B1, B2, and B3, respectively. These data make it clear that any trenching or drilling operation should stay well away from the site of Boring B3 which has a thick layer of very strong beachrock. Underneath the beachrock is a layer of poorly cemented sand mixed with coral fragments. This underlayer was easy to core into and should present no problem to drilling or trenching activities.



(from Chamberlain, 1965)

FIGURE 18: CROSS-SECTIONS OF BEACHROCK AT PMRF.

LAT 22° 3' 17.4127"  
LONG 159° 47' 12.2381"

PACIFIC OCEAN

PMRF

E1 BT=7.5 ft  
CS=3470 psi

R2 BT=8.0 ft  
CS=3120 psi

E3 BT=14.5 ft  
CS=1120 psi

N

200 ft

BT=BEACHROCK THICKNESS  
CS=BEACHROCK COMPRESSIVE  
STRENGTH

LAT 22° 2' 44.3325"  
LONG 159° 47' 16.4036"

FIGURE 19: BEACHROCK BORING STUDY.



## VI. CURRENTS

Coast and Geodetic Survey (1963) reports observed currents 0.5 miles off Mana Point to be 0.8 knots maximum to the south three hours after low water and 0.8 knots maximum to the north three hours after high water. Similar observations near the shoreline 3.5 miles southeast of Nohili Point showed the currents to be generally less than 0.5 knots.

Laevastu, Avery, and Cox (1964) summarize drogue measurements made of tidal currents around Kauai about two miles offshore in about 600 feet of water during 23-24 July 1963. Figure 20 from that report shows how the tidal currents flow around Kauai. The flood currents are to the south-southeast at the PMRF site, and to the north-northeast during ebb current. Maximum velocities were only one knot.

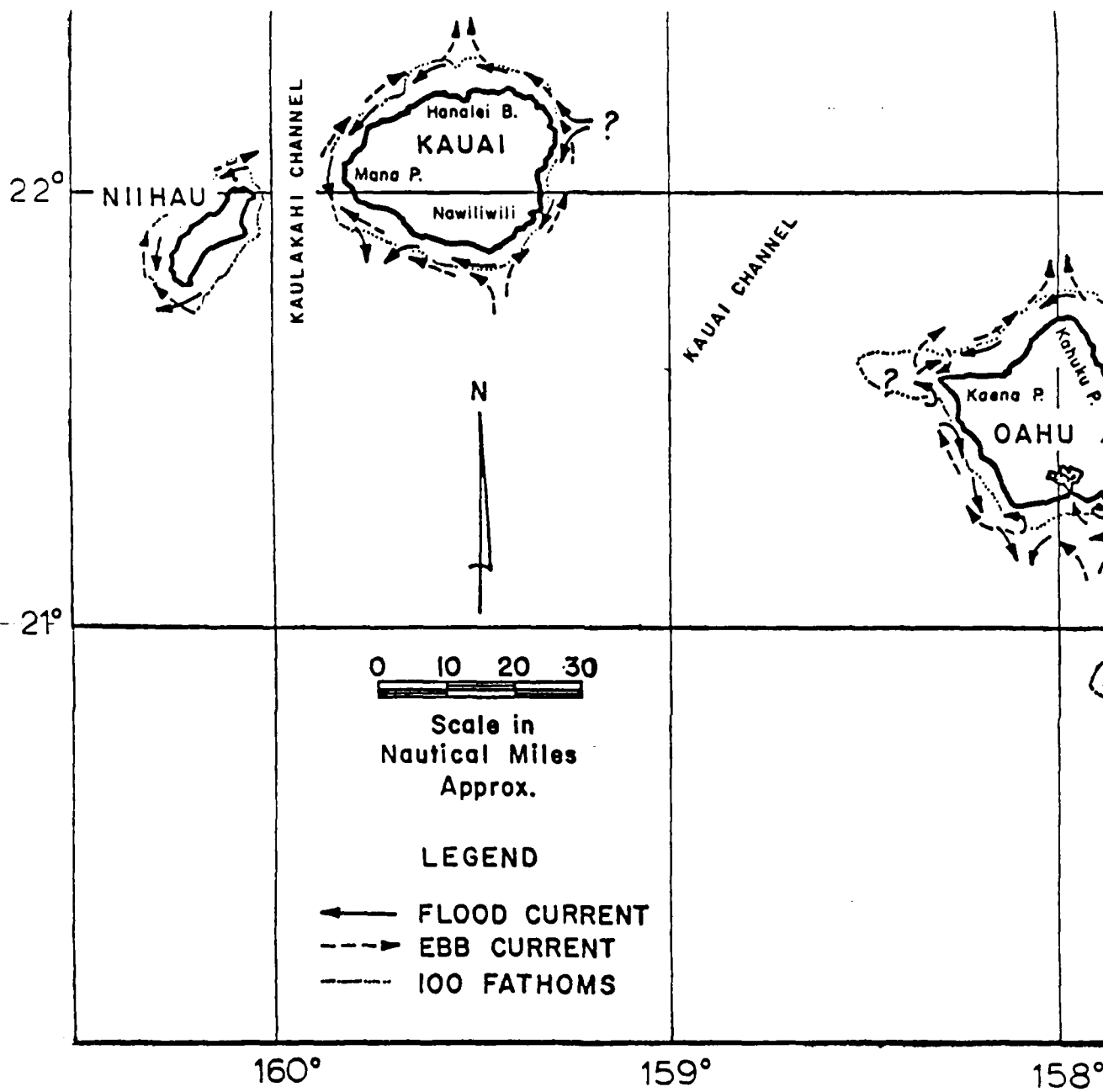
Corps of Engineers (1966) reports that during a storm in March 1965 with waves approaching from the northwest, a southward nearshore current of 3 knots was observed along with a rip current.

Between October 1967 and October 1968, seven measurements were made of the longshore currents outside of the breaker line, according to Corps of Engineers (1969). The readings were made eight feet below the surface in 20 feet of water. All currents were less than one knot and to the south. However, within the breaker zone, the maximum longshore current was 3 knots.

The Naval Oceanographic Office set up three bottom-mounted current meters from 16 July to 5 August 1974 in 40 feet to 80 feet of water, 0.5 to 1 mile offshore of Nohili Point, as shown in Figure 21 from Huddell and Willet (1977). The currents are seen to generally follow the direction of the bottom contours with a northeast-southwest orientation. Maximum currents were only one knot. The driving force of the currents was the tide, as can be seen in Figure 22 from Huddell and Willet (1977).

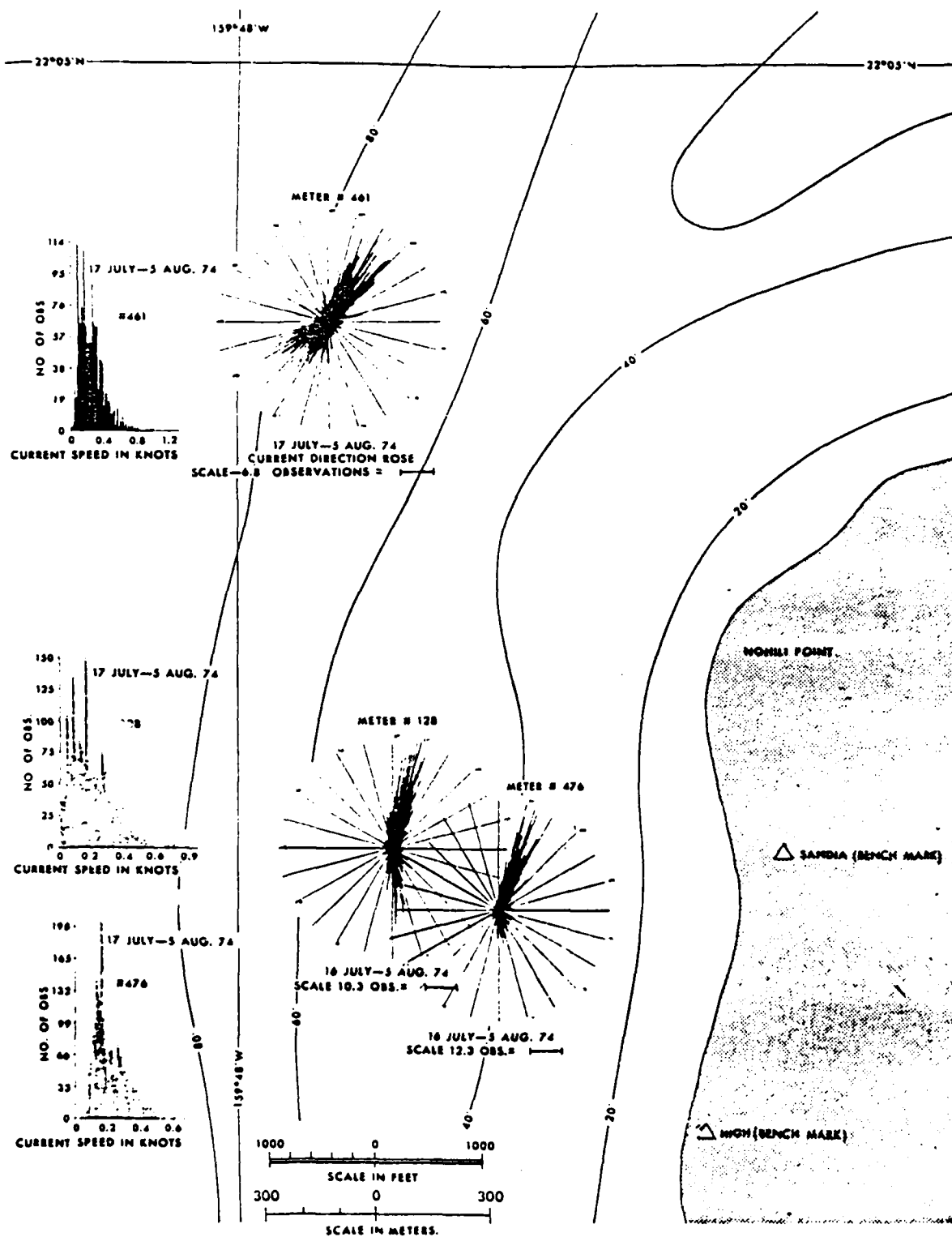
Corps of Engineers (1978) reports on two sets of nearshore current measurements taken in January 1977 near Kekaha. With westerly swell of five to eight foot breaker heights, the longshore current was southeasterly at 0.7 knots. The winds were light and variable. The second set of measurements were taken on a day when the winds were northeast trade winds and the waves were only one to three feet high. The currents were 0.4 to 1.5 knots to the west. These currents were not correlated with the tides.

From the above discussion, it is seen that nearshore currents are seldom more than one knot, except close to or within the breaker zone. In the latter case, currents of three knots were observed. Unfortunately, the number of observations is rather small and an estimate of a design current should be based on the wave climate and water depth at the point of interest, with one knot added to account for the tidal current.



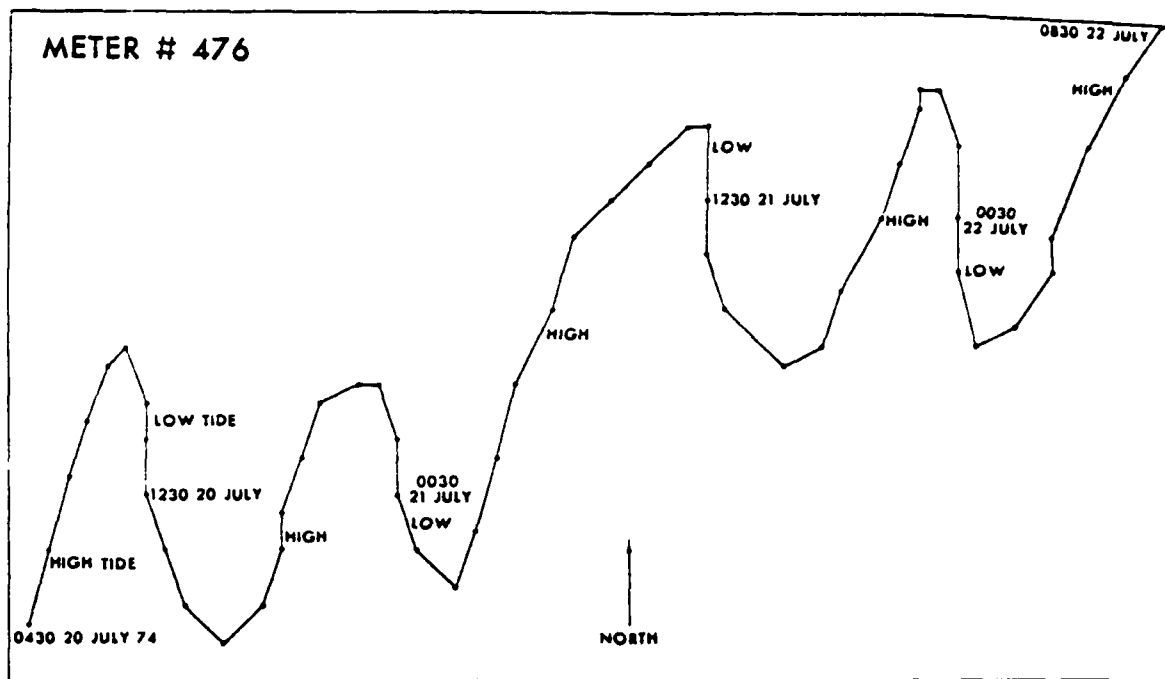
(from Laevastu, et al., 1964)

FIGURE 20: TIDAL CURRENTS AROUND KAUAI.

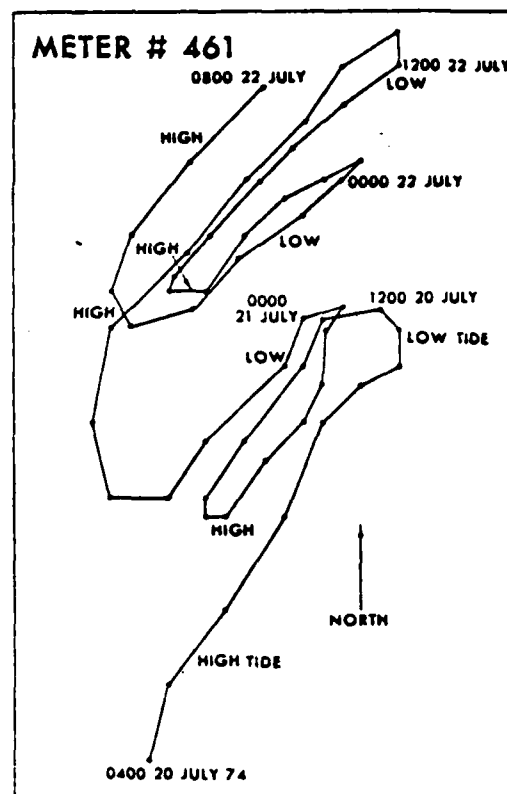
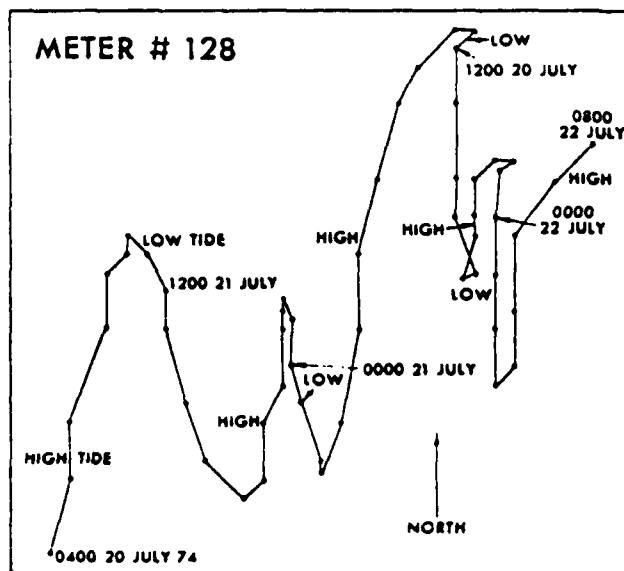


(from Huddell and Willet, 1977)

FIGURE 21: LOCATIONS AND VELOCITIES OF TIDAL CURRENT MEASUREMENTS.



1 NMI  
1 KM



(from Huddell and Willet, 1977)

FIGURE 22: VECTOR DIAGRAMS OF TIDAL CURRENTS (PATHLINES OF DROGUES),

## VII. SEDIMENT BUDGET

More than one-third of all the beach sand on the Hawaiian Islands is found on the island of Kauai. Also, Kauai has the largest ratio of sand volume to mile of coastline. This relative preponderance of sand can be attributed to the two major sources of sand for the island. The primary sand source is the biological production of sand by the offshore reefs. Since Kauai is older than the other Hawaiian islands, the reef structures of Kauai are larger and better developed. These reef structures, therefore, produce more sand relative to the other islands. On Kauai, the Barking Sands beach is by far the largest, with over 3.5 million cubic yards of sand (Chamberlain, 1968). Most of the sand which is biologically produced offshore is stored in the reefs and reef flats from which it can be moved rapidly onshore under the correct wave conditions (Chamberlain, 1968). Moberly and Chamberlain (1964) identify a broad bank offshore of Barking Sands beach in about 50 feet of water as a source of sand for the beach.

The Waimea River serves as the secondary source of sand for the beaches in the river's local area. Chamberlain (1968) estimates that 25,000 cubic yards per year of sand are brought to the littoral zone by the Waimea River, which has produced a nearshore sand reservoir of 10 million cubic yards, the largest in Hawaii.

The typical beach on the Hawaiian Islands has a littoral cell structure, which consists of two stable end points with a sandy beach in-between. The end points are usually rock outcrops or cliffs that resist erosion. Three cells can be defined for the Mana Plain, as illustrated in Figure 23: the shoreline from Nohili Point south to Mana Point, called the Nohili-Mana cell; the shoreline from Nohili Point northeast to Makaha Point, called the Barking Sands cell; and the shoreline from Mana Point southeast to the Waimea River, called the Kekaha cell. The PMRF is located within the Nohili-Mana cell.

The winter North Pacific swell produces a longshore transport to the southwest through the Barking Sands cell toward the Nohili-Mana cell. The summer southern swell produces a longshore transport to the northwest through the Kekaha cell toward the Nohili-Mana cell (Inman, Gayman, and Cox, 1963). However, the shoreline within the Nohili-Mana cell is not accreting as would be expected from this confluence of longshore transport. Instead, the shoreline is dominated by beachrock outcrops which are indicative of a non-accreting shoreline. Therefore, there must be an overall offshore movement of the sand which reaches the Nohili-Mana cell from the two adjacent littoral cells. Part of this offshore movement can be ascribed to a sand channel described by Chamberlain (1965) which runs from the shoreline out to a depth of approximately 13 feet near the cable landing site. Chamberlain also observed a rip current running offshore along this channel.

Sometimes, sea level rise can be an important factor in shoreline

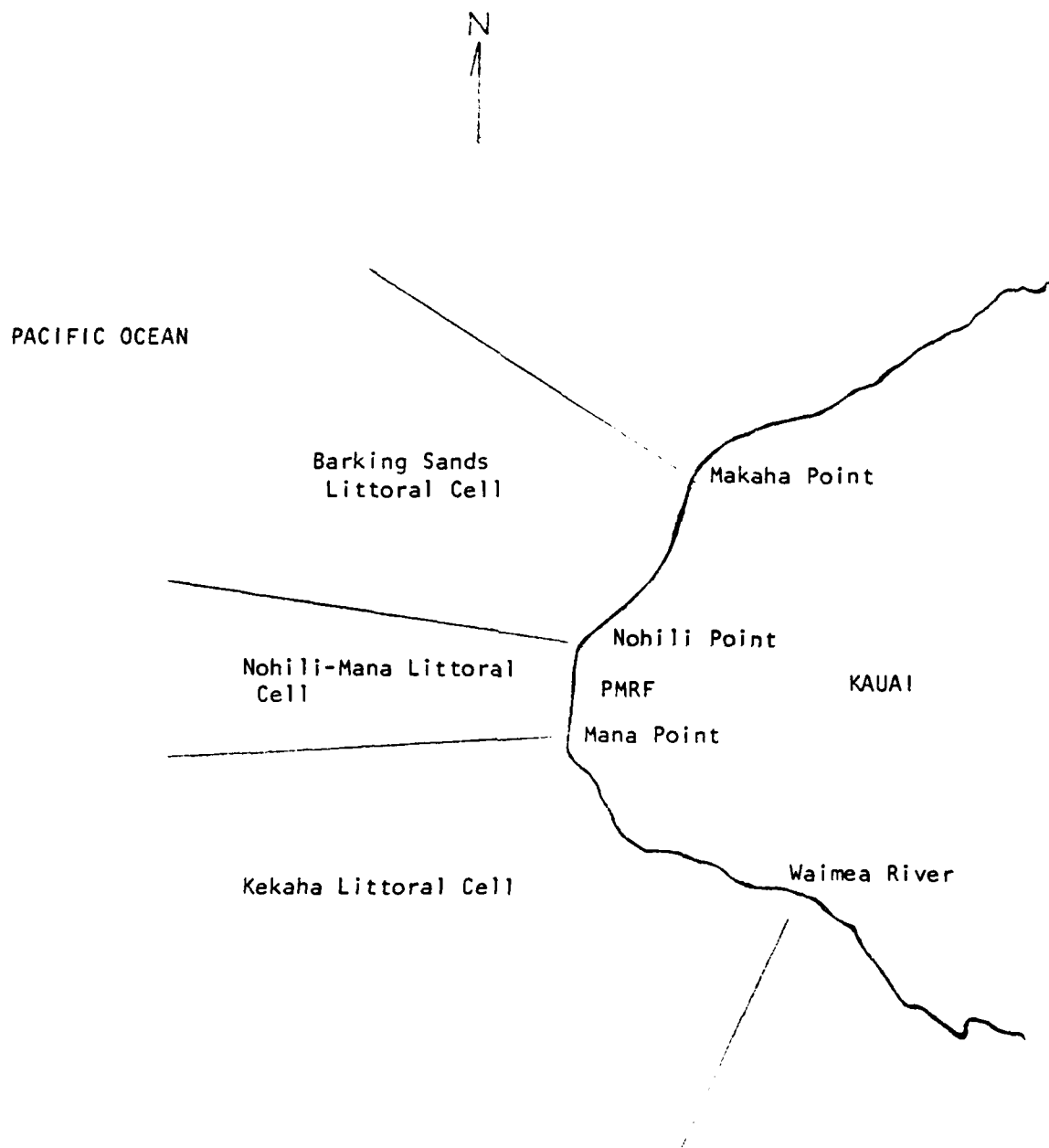


FIGURE 23: LITTORAL CELLS FOR THE WEST COAST OF KAUAI.

retreat. However, such is not the case in the Hawaiian Islands. Hicks, Debaugh, and Hickman (1983) reports the sea level rise at Honolulu to be 0.005 feet per year based on data collected since 1905. With the relatively steep 1 on 10 beach slope at the PMRF, the rise in sea level over the past twenty years, if it were the only factor acting, would have caused a shoreline retreat of only one foot.

The general description of sand movement can be summarized as follows. The dominant sand movement along most of the Mana Plain shoreline is the onshore transport of biologically produced sand from the offshore reefs. Sand is also moved alongshore and into the Nohili-Mana littoral cell from the two adjacent cells when the proper wave conditions exist. This longshore transport which enters the Nohili-Mana cell is then moved offshore resulting in a non-accretionary beach within the cell, as evidenced by the beachrock outcrops along the shoreline. Superimposed on these processes are the short-term perturbations of the seasonal offshore movement of sand in the winter and onshore movement in the summer.

### VIII. SUMMARY AND CONCLUSIONS

The climate of the PMRF site is mild, due to the influence of the surrounding ocean, and dry, due to the influence of Mt. Waialeale. There are only two meteorological seasons. The summer months are April through November, a time of strong northeast trade winds. The winter months are December through March, a time of lessened trade winds, increased southeasterly winds, and local storms. Tropical storms pass by about once every nine years.

The wind climate is dominated by the northeast trade winds, particularly during the summer months. Kauai's mountainous terrain, however, shelters the PMRF from many of these winds. ANSI standards give a 50-year design wind of 80 mph for Kauai.

Waves are composed of northeast trade waves, North Pacific swell, southern swell, and Kona storm waves. Fifteen years of surf observations clearly show the summer months to have much milder wave climates than the winter months. A nearshore wave gage was installed near the PMRF in October 1983 and will produce an excellent data set from which a design wave can be selected. The Corps of Engineers is also working on a wave hindcast of the offshore area.

The beach sand at the PMRF is of medium size, poorly-sorted, and tends to move offshore during the winter. Beachrock is prevalent around the study area and extends out to 200 feet offshore. It was found to be up to 14.5 feet thick with compressive strengths of up to 11,000 psi. The beachrock must be considered in any engineering design near the shoreline.

Nearshore current measurements are scarce. Those that have been taken give a maximum of three knots near or in the surf zone. However, design currents are best based on wave climate and water depth with one knot added for tidal current.

The beaches near PMRF are primarily composed of sand biologically produced offshore and moved onshore by the waves. Longshore transport tends to move sand towards the shoreline between Nohili Point and Mana Point where it is then moved back offshore. This offshore movement balances the longshore influx and produces a non-accreting shoreline, as evidenced by the exposed beachrock.

The best time of year to work at the PMRF site with regard to the wave environment is the summer, particularly during June, July, and August. However, summer is also the time of maximum beach sand thickness which makes work on the beachrock difficult. Therefore, if both large waves and beach sand are to be avoided, the early summer months of April and May are probably optimum. During these months, the waves are relatively low and the beach sand has not had much time to move back onshore.



The beachrock discussion of Section V and particularly Figure 17 suggests an absence of beachrock northeast of Nohili Point on the Barking Sands beach. This site should be considered for future cable landings since the cables could probably be buried in the sand. A subsurface investigation consisting of probings would be needed to confirm the absence of beachrock.

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